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FEATURES

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TRANSACTIONS
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A TWO-FOLD TRIUMPH

CAPTAIN CHARLES A. LINDBERGH, the hero of all nations, has without any question of a doubt performed the most spectacular feat for a single individual in all of the history of man's achievements. A modest, fearless, energetic and courageous American youth, he has accomplished what no other human being has ever been able to accomplish. The feat which he performed, single-handed, was one which has claimed the lives of several American air pilots and the two courageous French aces, Nungesser and Coli. In the face of the tremendously overwhelming odds, factors which might cause failure and disaster in the attempt to make a non-stop flight from New York to Paris in a heavier-than-air monoplane, Captain Lindbergh with full confidence in the ability of his Ryan monoplane, propelled by the marvelous Wright J-5C "Whirlwind" engine, was willing to stake his life to prove to the world that such a feat could be successfully performed. His previous training and experience in the air-mail service fitted him admirably for this supreme test of endurance and capacity for sustaining the hardships of a 34-hour flight over land and water for a distance of nearly 4,000 miles.

The spontaneous enthusiasm which has characterized his reception in England and France and the unanimous approbation of all Americans is more than significant that all of the world consider this achievement as the greatest that has ever been attained. His marvelous flying sense and his super capacity in navigating his ship has thrilled all mankind, and we are unstinting in wholesouled praise of Captain Lindbergh's success. We admire him, honor him and praise him.

We are, however, not unmindful of a secondary triumph which has been performed in the success of this flight. It is a triumph in engineering and one which Captain Lindbergh has put foremost, —the mechanical perfection of his plane. How natural it must be

for him to regard his airplane as a living companion on this flight, and how unaffected has been his use of the editorial "we" in sharing the credit with his mechanical accomplice.

Since the accomplishment of this successful endeavor, the press of the entire world has devoted much space in recogition of this flight. No doubt all of the details of all phases of this accomplishment have already been discussed, but perhaps not completely so in the light of the engineering achievement. While it is true that Captain Lindbergh flew alone across the Atlantic Ocean, he did have many silent partners. These partners were the engineers, the designers, the mechanics, the metallurgists and steel treaters who, through years of experience and development, have made it possible to construct an engine and the necessary accompanying accessories and instruments that could and would function successfully for long continuous operation. The 508 pounds of metal, alloyed, worked and heat treated to such a degree that it was capable of lifting a total weight of 5150 pounds off the ground and carry it nearly 4000 miles at an average speed of 100 miles per hour is nothing short of marvelous. This is the accomplishment of the 200-horsepower Wright "Whirlwind" engine, air-cooled, of the fixed radial type with nine cylinders. The metallurgist had much to do with this 500 pounds of metal. It is indeed a metallurgical achievement wherein more than 100 companies participated in furnishing materials, parts or service. Practically every important American industry participated in the manufacture of the airplane.

The valves were of the salt-filled type, made of heat treated tungsten steel. The pistons were made of a heat treated cast aluminum alloy. The crankshaft, connecting rods, wrist pins and other steel parts were of alloy steel, heat treated to obtain the highest performance possible. It is gratifying to realize that many members of the A. S. S. T. contributed directly to the success of Captain Lindbergh's success of successes.

VOLUME XI COMPLETED

THIS issue of TRANSACTIONS completes Volume XI which covers the period from January, 1927, through June, 1927. Volume XII will include the period from July, 1927, through December, 1927. The index for Volume XI is now ready and may be secured upon request.

Those desiring to have their loose copies of Volume XI bound in accordance with the style used in binding Volumes I-X inclusive, may do so by forwarding them to the executive offices of the Society, 4600 Prospect Avenue, Cleveland, together with $2.00, and they will be bound and returned promptly.

COMPARISON OF THE ALLOYING ELEMENTS CHROMIUM, NICKEL, MOLYBDENUM AND VANADIUM IN STRUCTURAL STEELS

By H. J. French

Prefatory Abstract

A brief discussion is given of the effects of chromium, nickel, molybdenum and vanadium in structural steels. Comparisons are made of commercial low-alloy steels containing one or more of the specified elements on the basis of their making and shaping, machining, heat treatment, etc. The current high-alloy content steels for resisting corrosion or high temperatures are described and consideration given to wear as affected by each of the elements, chromium, nickel, molybdenum and vanadium. The report is a condensed summary of important characteristics of alloy steels containing the specified elements and is illustrated by practical applications.

I. Introduction

IN THE following discussion the term "structural steels" applies to those steels which are used primarily in structural members (not only in buildings, bridges etc., but also in machines and the like) as distinct from the group which is employed in the cutting and forming of metals, customarily referred to as tool steels.

It is also necessary to restrict the discussion of alloying elements to those in most common use, chromium, molybdenum and vanadium. It is only fair to point out, however, that the cheaper, more prosaic and lowly elements, manganese, silicon and perhaps copper, when used in amounts larger than those in which they appear in plain carbon steels, are also alloying elements. They confer upon steel, to a more or less marked degree, attributes similar to those conferred by the "four horsemen." It is a fair question whether manganese, at least, does not deserve attention equal to that paid the four elements upon which comment will be made.

Consideration of the effects of these four elements only and

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A paper presented before the Pittsburgh Chapter, March, 1927. The author, H. J. French, is senior metallurgist, department of metallurgy, Bureau of Standards, Washington.

in structural steels, only, opens a broad field and the subject, even with the restrictions mentioned can scarcely be considered in great detail within the space allotted. It would, therefore, seem advantageous to further restrict the discussion to the general effects of these elements upon iron and iron-carbon alloys and to emphasize some few outstanding characteristics or important applications of the commercial products.

During recent years the types commercially produced have increased in number, and there has been a gradual but important broadening of their fields of application. This has been directed not only to use in structures subjected to severe service, involving fatigue, high temperatures, corrosion or wear, but engineers have considered more extensive application of them, often as a means of saving weight under the more ordinary requirements which chiefly involve static stress. With such a broad field to cover it is not possible to discuss all of the important types of steel nor can consideration be given to more than a few of the principal characteristics of any one group. Little new information is given, but data have been selected to give a picture of the field with respect to the nature and properties of current structural alloy steels containing one or more of the four elements under discussion.

Until recently, alloy steels of this group have contained relatively small proportions of the alloying elements, amounting to not more than about 5 or 6 per cent in any given type. There were, of course, some notable exceptions such as the Hadfield steel which contains about 14 per cent of manganese, and some of the high nickel steels, but in general only small proportions of special elements were used in the commercial steels. While low alloy content steels still account for the largest proportion of alloy steel tonnage there is for severe service a noticeable trend toward wider application of steels containing high proportions of special elements because of the special properties secured. In the succeeding discussion these two groups will be considered separately.

II. Importent Effects Produced in Steels by Chromium, Nickel, Molybdenum and Vanadium.

Little space need be given to a detailed discussion of the effects of chromium, nickel, molybdenum or vanadium upon the constitution, thermal critical points and associated properties of steels, for these subjects are discussed in most texts relating to

ferrous metallurgy or heat treatment. There are, however, a few outstanding features which can be considered to advantage as they will help form a picture of the relative usefulness and major influences of each of the specified elements.

As shown in Table I, nickel is used in larger percentages in

Table I

Some Important Features of Nickel, Chromium, Molybdenum and Vanadium Steels

Special Element	Nickel Per Cent	Chromium Per Cent	Molybdenum Per Cent	Vanadium Per Cent
Proportions in commercial structural steels	0-46	0-30	0-1	0-0.4
Used alone or with other special elements	Both	Both	Largely in combination	Largely in combination
With	0-5% Ni	0-2% Cr	0-1% Mo	0-0.4% V
Critical range	Lowered	Raised on heating, lowered on cooling	Split	Little effect
Present in steel as	Solid solution in ferrite	Carbide with iron and chromium. In large amounts also in ferrite	Solid solution in ferrite. Formsiron-molybdenum compound according to Swinden	Partly in iron and partly in carbide
Outstanding effects in steels	Increases hardness without the decrease in toughness	High resistance to permanent deformation (high hardness)	Confers air-hardening properties	De-gasifying properties; keeps grain size small

commercial steels than either chromium, molybdennm, or vanadium. Chromium, however, is now a close second in this respect,

whereas molybdenum and vanadium have been held to small amounts in the structural steels.

These four elements again fall into the same two groups when considering their use alone or in combination with other elements. Nickel and chromium are used either alone or with other special

Fig. 1—Delaware River Bridge, Completed in 1926, in which 3 per cent Nickel Steel was used in the Stiffening Trusses. (Courtesy of International Nickel Co.)

elements in steels, whereas molybdenum and vanadium are most often used in combination with metals like chromium, nickel, manganese, etc. When in such company they are often credited with the ability to itensify the effects of their companions.

One of the most important effects of small additions of nickel to steels is the increase in strength or hardness obtained without appreciable decrease in ductility. This is observed with 3 to 4 per cent of nickel in hot-finished as well as heat treated alloys and in low carbon as well as medium carbon steels. On this account nickel is one of the special elements used in steels rolled into structural shapes. A comparatively recent application in this field is found in the construction of the Delaware River Bridge, a photograph of which is shown in Fig. 1. This bridge was completed during 1926. Structural steels containing 3 per cent nickel were used in the stiffening trusses.

Nickel. Nickel is soluble in all proportions in iron in both liquid and solid states and in steels is, therefore, in solid solution in the ferrite. It lowers the temperatures of the transformations

(critical ranges) on both heating and normal slow cooling. With about 10 per cent nickel the critical ranges occur at atmospheric temperatures.

Low temperature critical ranges permitting low hardening temperatures are advantageous as under such conditions, the steel has less tendency to distort and to scale. However, these features are more often less important than the improved mechanical properties of the nickel steels already referred to.

Chromium. Chromium is a carbide-forming element and combines with the carbon in steels to form what is probably an iron-chromium-carbide. Under these conditions it is only natural that the effects of chromium should be quite largely dependent upon the carbon present in the steel. Chromium steels are quite generally "sluggish" in their reactions as shown by the fact that the A_3 point is raised on heating and lowered on normal slow cooling. One of the outstanding characteristics of steels containing 1 to 2 per cent chromium and appreciable proportions of carbon is their high hardness or resistance to permanent deformation when in the hardened conditions. In large proportions chromium confers upon steels exceedingly valuable corrosion-resistant and heat-resistant properties which will later be referred to in greater detail.

Molybdenum. Molybdenum which is one of the recent additions to the list of special elements found in commercial structural steels, is unique in its ability to confer "air-hardening properties" on steels when added in such small proportions as, with most other elements, would hardly cause any noticeable effect. While commercial molybdenum steels are of comparatively recent origin, some of the beneficial effects produced by molybdenum in structural steels were known or suspected many years ago.

Vanadium. Vanadium is the least important of the four metals under consideration and is used only in small doses in structural steels. In the proportions normally present it is considered to be partly in the ferrite and partly in carbide. It is very effective in keeping grain size small in both castings and forgings, a feature which appears to be concomitant with high elastic properties. These characteristics make annealed vanadium steels, particularly in large sections where quenching would introduce serious difficulties, useful in the production of large forgings such as the submarine crankshaft shown in Fig. 2. Cast vanadium steels have been quite widely used in locomotive frames, a typical

example of which is shown in Fig. 3. While these and many other applications can be cited for vanadium structural steels, there are important fields where vanadium is losing ground.

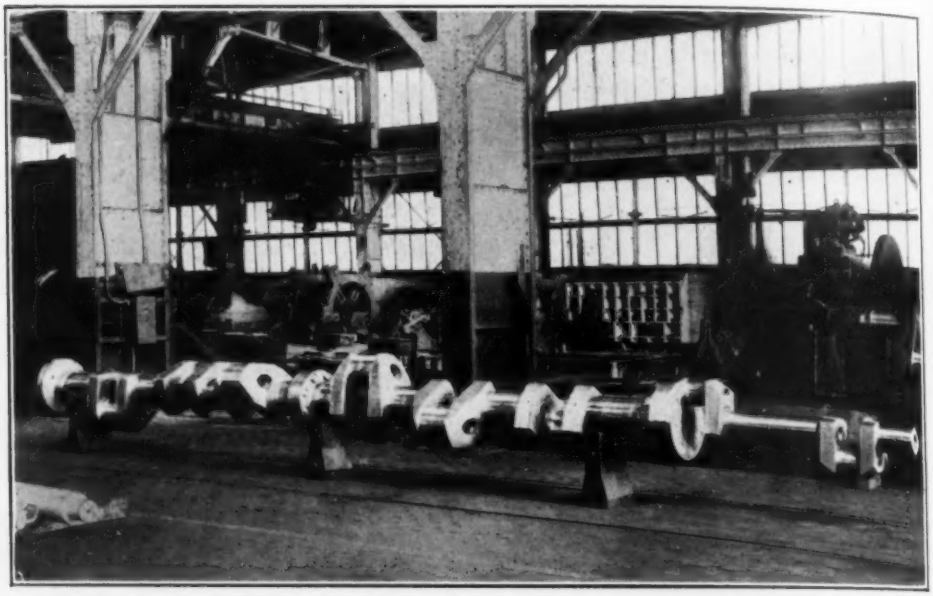


Fig. 2—Submarine Crankshaft made from an Annealed Vanadium Steel Forging. Made by Erie Forge Company, Erie, Pa. (Courtesy Vanadium Corp. of America.)
Pins and Journals, 12½ inches; Bore, 4¾ inches; Throw, 10⅜ inches; Length, 30 feet, 8½ inches.
Chemical Composition:—Carbon, 0.38%; Manganese, 0.58%; Vanadium, 0.13%. Approximate average properties: Tensile strength, 78,000 pounds per square inch; Yield Point, 46,000 pounds per square inch; Elongation, 31.5 per cent in 2 inches; Reduction of Area, 58.5 per cent.

Fig. 3—Cast Vanadium Steel Locomotive Frame. Manufactured by Union Steel Castings Co., Pittsburgh, Pa., for the Norfolk and Western Railway. (Courtesy Vanadium Corp. of America.)
Finished casting 32½ feet long, weight 12,000 pounds.

Reference has frequently been made to the powerful "cleansing" action of vanadium, but its value in this direction would seem to be largely a question of the purpose for which the finished

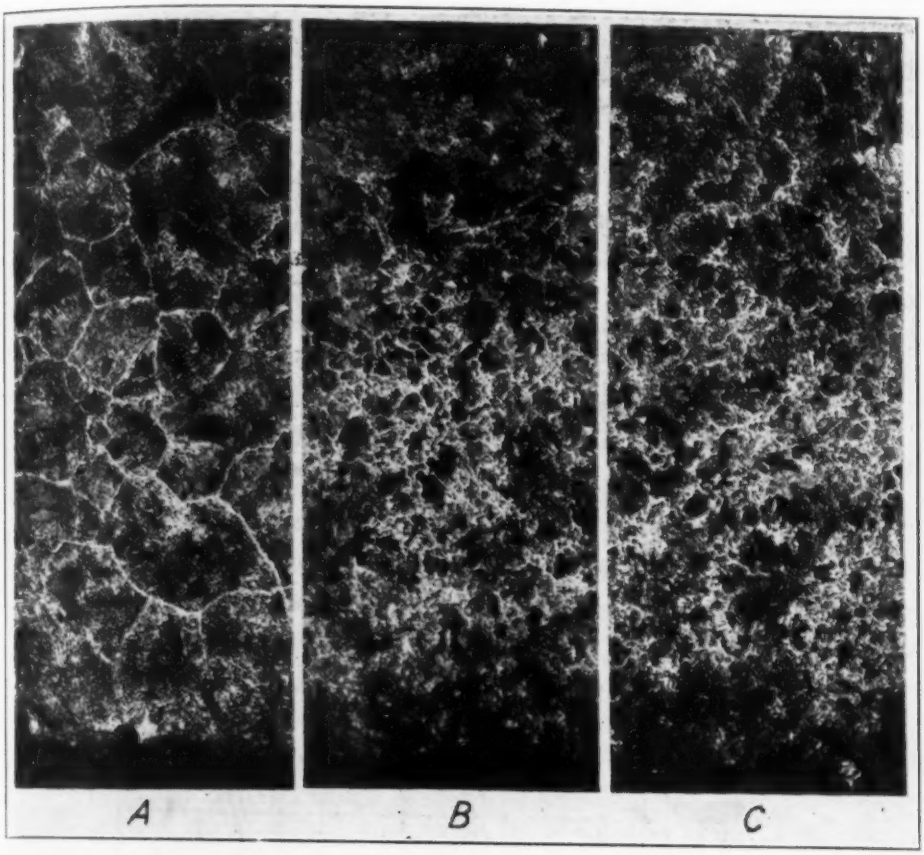


Fig. 4—Photomicrographs Showing the Effect of Mold Additions of Vanadium or Aluminum on the Structure of Low Carbon Steel in the McQuaid-Ehn Carburizing Test. (Courtesy of S. Epstein, Bureau of Standards.)

Note the similarity in stuctures of the steels treated with aluminum and ferrovanadium. All ingots from one heat made in regular production. Ladle test 0.14 per cent carbon, 0.44 per cent manganese. Fig. 4A—Steel of above analysis as cast. Fig. 4B—Steel of same analysis but with addition of 0.04 per cent aluminum. Fig. 4C—Same steel but with addition of 0.1 per cent vanadium.

steel is desired. For example, treatment of low-carbon steel in the mold with ferrovanadium was found by Epstein[1] to produce the fine grain and divorced cementite in the McQuaid-Ehn carburizing test, shown in Fig. 4, and the tendency toward formation of "soft spots" in ordinary water quenching, characteristic of "abnormal" steels. The cause of such effects is still obscure but is thought to be associated with the crystallization centers offered by

[1]Unpublished test data secured at the Bureau of Standards. See also S. Epstein and H. S. Rawdon: Progress in Study of Normal and Abnormal Steel. Preprint of paper presented at Winter Sectional Meeting, American Society for Steel Treating, Washington, D. C., January 21, 1927.

vanadium compounds, ordinarily in too fine a state of division to be seen under the microscope, which do not coagulate when the vanadium is added in the mold. Such compounds may be vanadium carbides, oxides or nitrides.

III. Low Alloy Content Steels as a Class

Generally speaking, none of the metallic elements ordinarily added in small proportions to iron, is as effective a hardener as is carbon. Thus while the addition of about 1 per cent of chromium, nickel, molybdenum or vanadium to iron low in carbon or iron

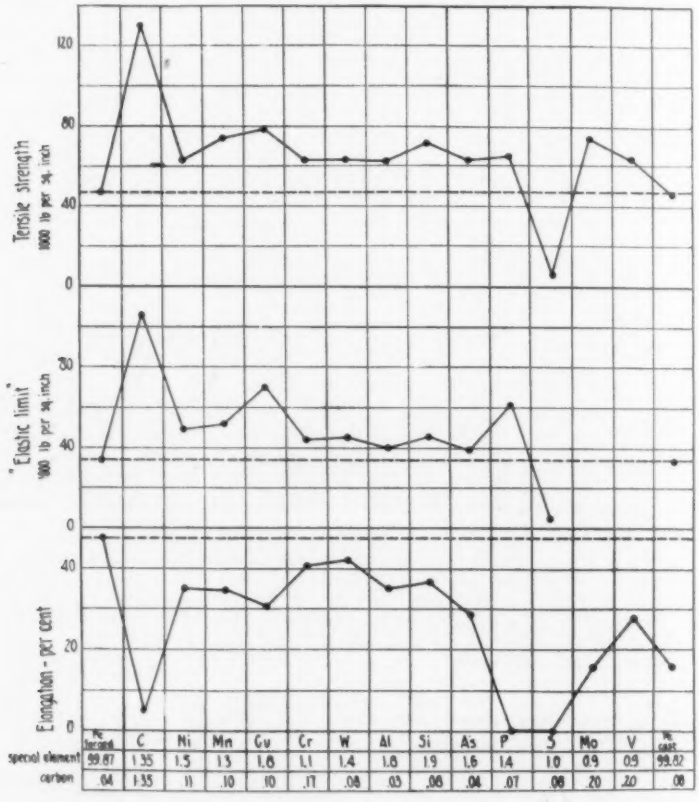


Fig. 5—Effect of 1 to 2 per cent of Special Elements on the Tensile Properties of Iron (after Hadfield, based on data obtained by Arnold). Data for Molybdenum and Vanadium added by the author.

containing moderate amounts of carbon increases tensile strength and hardness in the cast, normalized or "natural" conditions, this increase in strength and decrease in ductility is not of the same order as that produced by similar additions of carbon. This has long been known and is illustrated in Fig. 5 in which are sum-

marized graphically experiments recorded by Arnold[2] over thirty years ago, together with data for vanadium and molybdenum added by the writer.

When considering quenched or quenched and tempered steels, a somewhat different condition is found. While it is possible to produce high strength in plain carbon steels, this is accompanied by a marked decrease in toughness, whereas in the alloy steels the high hardness produced by quenching is not obtained at such a great sacrifice of toughness. It is largely for this reason that the alloy steels have found important applications in automotive, ordnance and machine construction. Mere strength and hardness, i. e., resistance to permanent deformation are rarely the sole requirements in structural work because, aside from the stresses which are normally encountered, most engineering structures may at some time or another be subjected to shocks or overloads that would be dangerous to brittle materials. Under such conditions, toughness, a high degree of ductility in addition to strength, is important and represents an insurance factor which should not be neglected.

The commercial low alloy content steels containing one or more of the elements chromium, nickel, molybdenum, or vanadium, which have been so intimately connected with the development of the automotive industry are well standardized despite the occasional or even frequent applications of special compositions to meet specific requirements. This group is so well known that typical compositions need not be reproduced in this report[3]. These steels are primarily of interest for their mechanical properties which will therefore be the basis for comparison.

Disregarding for the present all questions of cost, the low alloy structural steels may be said to be interchangeable to a large degree insofar as their mechanical properties are concerned. Such interchangeability with respect to hardness, combinations of tensile strength and ductility, resistance to impact or fatigue etc., can only be obtained, however, by suitable regulation of the added elements, particularly in relation to the carbon content of the steel, combined with appropriate modifications in heat treatment.

[2]J. O. Arnold: The Physical Influences of Elements on Iron, *Journal,* Iron and Steel Institute, 1894, Part I, page 107.

[3]Refer to the specifications of the Society of Automotive Engineers, 29 West 39th Street, New York.

Table II

Comparison of the Mechanical Properties of Different Steels when Heat Treated so as to Produce the same Tensile Strengths (after Gillett and Mack)

STEELS OF ABOUT 100,000 TENSILE STRENGTH

Composition								Quench			Temper			Mechanical Properties				
C	Si	Mn	Ni	Cr	V	Mo	Zr	° C.	° F.		° C.	° F.	T. S.	P. L.	E. L.	Y. P.	Elong.	R. A.
.26	.20	.50	....	....	...	...	...	870	1600	water	400	750	100,000	.....	.....	74,000	25	58
.37	.16	.58	....	....	...	...	...	845	1550	do.	565	1050	102,500	80,500	.....	87,500	23.5	65
.45	.32	.78	....	....	...	...	...	870	1600	do.	700	1290	100,000	.....	.....	72,000	28	67
.36	.05	.44	....	.57	...	...	...	815	1500	oil	650	1200	96,000	.....	69,000	.....	25	60
.34	.15	.87	....	....	.13	...	...	875	1610	do.	600	1110	102,500	.....	85,000	.....	22	57
.37	.20	.65	3.50	....	...	...	...	800	1475	do.	650	1200	100,000	.....	58,000	.....	27.5	66
.20	.22	.41	....	....	...	.94	...	830	1525	do.	675	1250	102,000	90,000	.....	.....	22	64
.32	.21	.63	....	....	...	.83	...	845	1550	do.	675	1250	108,000	.....	97,000	.....	23	66
.42	.15	.75	....	1.04	.15	...	...	870	1600	do.	750	1380	103,000	.....	90,000	.....	30	68
.32	.15	.55	....	.90	...	.37	...	925	1700	do.	760	1400	100,000	.....	80,000	.....	29	71
.17	.15	.37	2.95	.45	...	...	...	820	1510	do.	540	1000	100,000	.....	77,000	.....	26	68
.35	.15	.57	1.60	1.18	...	...	...	850	1560	do.	700	1290	115,000	.....	.....	92,000	24	70
.40	.15	.60	1.25	.60	...	...	...	850	1560	do.	595	1100	100,000	74,000	.....	.....	24.5	71

STEELS OF ABOUT 125,000 TENSILE STRENGTH

Composition								Quench			Temper			Mechanical Properties				
C	Si	Mn	Ni	Cr	V	Mo	Zr	° C.	° F.		° C.	° F.	T. S.	P. L.	E. L.	Y. P.	Elong.	R. A.
.20	.30	.75	....	....	...	...	...	900	1650	water	325	615	125,000	.....	.....	94,000	13	33
.45	.20	.60	....	....	...	...	...	890	1635	do.	205	400	125,000	90,000	.....	.....	12.5	35
.45	.32	.78	....	....	...	...	...	870	1600	do.	540	1000	125,000	.....	.....	100,000	23	57
.55	.27	1.25	....	....	...	...	...	?	....	?	?	....	132,000	.....	115,500	.....	12	48
.47	.11	.60	.51	....	...	...	...	795	1460	oil	705	1300	121,000	.....	110,000	.....	25	67
.34	.20	.87	....	....	.13	...	...	845	1550	water	565	1050	125,000	.....	109,000	.....	19	60
.37	.20	.65	3.50	....	...	...	...	800	1470	oil	480	900	125,000	.....	110,000	.....	18	58
.20	.22	.41	....	....	...	.94	...	910	1670	water	600	1110	125,000	105,000	.....	.....	17	59
.32	.21	.63	....	....	...	.83	...	845	1550	oil	595	1100	124,000	.....	108,000	.....	20.5	63
.42	.15	.75	....	1.04	.15	...	...	870	1600	do.	680	1250	125,000	.....	.....	110,000	24	57
.27	.20	1.01	....	.88	...	.52	...	845	1550	do.	650	1200	125,000	95,000	.....	.....	20	62
.32	.15	.55	....	.90	...	.37	...	870	1600	water	700	1290	125,000	.....	110,000	.....	24	66
.37	.15	.55	1.35	.42	...	...	...	800	1470	oil	590	1090	125,000	.....	100,000	.....	18	58
.40	.20	.63	3.00	.75	...	...	...	790	1450	do.	625	1150	125,000	.....	110,000	.....	20	61

Table II—Continued

Composition								Quench			Temper		Mechanical Properties				
C	Si	Mn	Ni	Cr	V	Mo	Zr	°C.	°F.		°C.	°F.	T. S.	P. L.	E. L.	Y. P.	Elong.	R. A.
STEELS OF ABOUT 125,000 TENSILE STRENGTH (Continued)																		
.32	.12	.46	3.70	1.42	...	...	...	820	1510	air	650	1200	125,000	.....	.....	103,000	25	67
.29	.14	.62	2.48	....	...	.52	...	845	1550	water	650	1200	121,000	.....	116,000	.....	22	62
.39	.15	.48	....	1.05	.17	.87	...	870	1600	oil	760	1400	125,000	.....	90,000	.....	28	66
.70	.26	.62	....	....	...	...	.15	825	1520	water	600	1110	125,000	.....	.....	105,500	21	55
.70	.26	.62	....	....	...	...	...	825	1520	do.	600	1110	127,000	.....	.....	110,000	19.5	51
STEELS OF ABOUT 225,000 TENSILE STRENGTH																		
.40	.29	.77	....	....	...	...	...	870	1600	water	300	570	225,000	.....	183,000	.....	6.5	17
1.04	.14	.17	....	....	...	...	...	845	1550	oil	315	600	228,000	146,000	.....	.....	8	20
1.20	.19	.25	....	....	...	...	...	800	1470	do.	345	630	225,000	136,000	.....	.....	3.5	6
.57	1.22	.61	....	....	...	...	...	825	1520	do.	500	930	219,000	.....	204,000	.....	5.5	15
.50	.20	.55	....	1.00	...	...	...	790	1450	do.	430	800	230,000	.....	197,000	.....	10	41
.64	.17	.28	....	1.04	...	...	...	870	1600	do.	400	750	227,500	.....	170,000	.....	5	13.5
.99	.14	.26	....	....	.32	...	...	850	1560	do.	600	1110	217,000	.....	160,000	.....	9	26
.41	.42	.72	....	....	...	.67	...	870	1600	water	360	680	223,000	.....	190,000	.....	12.5	52
.32	.21	.63	....	....	...	.83	...	845	1550	oil	205	400	232,000	.....	218,500	.....	10	44.5
.37	.20	.65	3.50	....	...	...	...	800	1470	do.	270	520	225,000	.....	208,000	.....	12	43
.33	.15	.40	5.00	....	...	...	...	800	1470	do.	260	500	225,000	.....	200,000	.....	13	51
.20	.20	.40	3.42	....	...	.51	...	845	1550	water	205	400	214,500	.....	191,500	.....	13	45.5
.43	.46	1.24	....	....	...	.73	...	875	1610	oil	400	750	221,500	.....	180,000	.....	13	49
.40	.20	.60	....	1.00	.18	...	...	900	1650	do.	425	800	226,000	.....	200,000	.....	10	45
.50	.07	.90	....	1.02	.20	...	...	900	1650	do.	450	840	227,000	.....	217,000	.....	10	35.5
.32	.15	.55	....	.90	...	.37	...	870	1600	water	250	480	225,000	.....	205,000	.....	11	47
.40	.40	.62	....	.95	...	.68	...	900	1650	oil	425	800	219,000	.....	170,000	.....	12	43
.37	.15	.55	1.35	.42	...	...	...	820	1510	do.	315	600	225,000	.....	218,000	.....	8.5	33
.41	.25	.75	3.41	.18	...	...	...	790	1450	do.	315	600	226,000	189,000	.....	196,500	7.5	56.5
.40	.20	.63	3.00	.75	...	...	...	790	1450	do.	330	625	225,000	.....	200,000	.....	11	48
.41	.15	.40	3.50	1.50	...	...	...	780	1435	do.	360	680	225,000	.....	208,000	.....	12.5	47.5
.32	.12	.46	3.70	1.42	...	...	...	820	1510	air	200	390	225,000	.....	196,000	.....	11	44
.41	.41	.64	1.27	.67	...	.83	...	825	1520	oil	460	860	224,000	.....	180,000	197,000	12.5	46
.41	.31	.60	2.49	.79	...	.76	...	805	1475	do.	425	800	223,000	190,000	195,000	.....	12	40.5
.39	.20	.48	....	1.05	.17	...	.87	870	1600	do.	395	740	225,000	.....	205,000	.....	11	45
.70	.26	.62	....	....	...	.15	...	825	1520	water	375	705	227,000	.....	.....	186,000	8.5	23

1. *Their Mechanical Properties*

A complete study of this question in the light of existing data was recently made by Gillett and Mack[4], and some of the data assembled by them will serve to support and amplify this view. Typical results obtained in small sections in the heat treatment of steels containing different combinations and proportions of alloy-

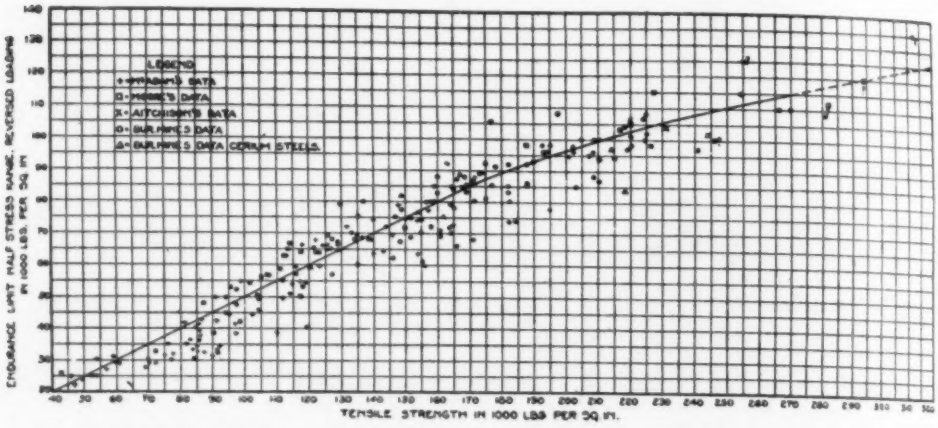

LEGEND
1- MOORE'S DATA
2- AITCHISON'S DATA
3- BURNHAM'S DATA
4- BURNHAM'S DATA CERIUM STEELS
ENDURANCE LIMIT HALF STRESS RANGE, REVERSED LOADING IN 1000 LBS. PER SQ. IN.
TENSILE STRENGTH IN 1000 LBS PER SQ IN.

Fig. 6—Relation between Endurance Limit and Tensile Strength for Carbon and Alloy Steels varying widely in Chemical Composition (after Gillett and Mack).

ing elements are given in Table II and Fig. 6. In many cases cited in Table II, it has been possible to produce, for all practical purposes, the same tensile properties by modifying the heat treatment to suit the selected composition. This applies not only to tensile strengths in the neighborhood of 100,000 pounds per square inch, but also to those in the neighborhood of 225,000 pounds per square inch or more.

Similarly, it is shown in Fig. 6 that the endurance limits of a wide variety of steels treated in various ways, fall within a fairly narrow zone about the smooth curve. Such differences as exist are due in part to difficulties in reproducing test conditions. But in any case, there is, as shown in Fig. 6 and Table II, the practicability of substitution of some of these alloying elements or combinations of alloying elements for others. What then, are the factors other than cost, which may influence the selection of a particular type of structural alloy steel?

To throw some light on this question, comparisons will be made of typical steels, such, for example, as 3.5 per cent nickel, 1

[4]H. W. Gillett and E. L. Mack: Molybdenum, Cerium, and Related Alloy Steels, The Chemical Catalogue Co., New York, 1925.

per cent chromium, nickel-chromium, chromium-vanadium, and chromium-molybdenum steels of the customary types.

IV. Some Comparisons of the Customary Nickel, Chromium, Chromium-Vanadium, Chromium-Molybdenum and Nickel-Chromium Steels.

1. *Their making and shaping*

No great difficulties are encountered in the making and shaping of any of these steels although the nickel steels are more apt to be seamy than the chromium or chromium-molybdenum steels. According to Camp and Francis[5], the power required to shape the customary chromium-molybdenum steel at hot working temperatures is somewhat greater than that required under otherwise comparable conditions for the customary nickel, chromium, and nickel-chromium steels. There was, however, no marked difference in these steels, (of forging grades containing about 0.35 per cent carbon), in the filling of passes in rolling nor in the tendency for surface defects to be rolled or forged out. The retention of relatively high hardness at high temperatures by the steels containing molybdenum is associated with other useful properties to which reference will be made later.

While differences are found in the mechanical properties at hot working temperatures, they are not large as is indicated in Fig. 7. In place of compression or Brinell hardness tests such as were carried out by Camp and Francis, these results were obtained in single-blow drop tests, and represent conditions more nearly comparable to drop forging. The relatively small differences between the structural steels will be evident by comparison with the curves for a high speed tool steel.

These comparisons are in general agreement with practical experience in drop forging, but do not throw light upon important differences which are not closely connected with the actual processes of deformation but rather with the heating and cooling cycle. Cracked forgings may frequently be traced to a poor surface condition of the billets, and hence any characteristic which promotes good surface proves advantageous from the standpoint of commercial shaping of the structural steels. The tendency for the nickel steels to show seams means a tendency toward poor surface, and,

[5] J. M. Camp and C. B. Francis: The Making, Shaping and Treating of Steel, 4th Edn., 1925, Carnegie Steel Company, Pittsburgh.

without suitable precautions, more trouble with defective forgings than when using the chromium-molybdenum or chromium-vanadium steels.

Another factor in favor of the molybdenum steels relates to the formation of scale at rolling or forging temperatures. The scale formed on the nickel steels, and to a lesser degree on the

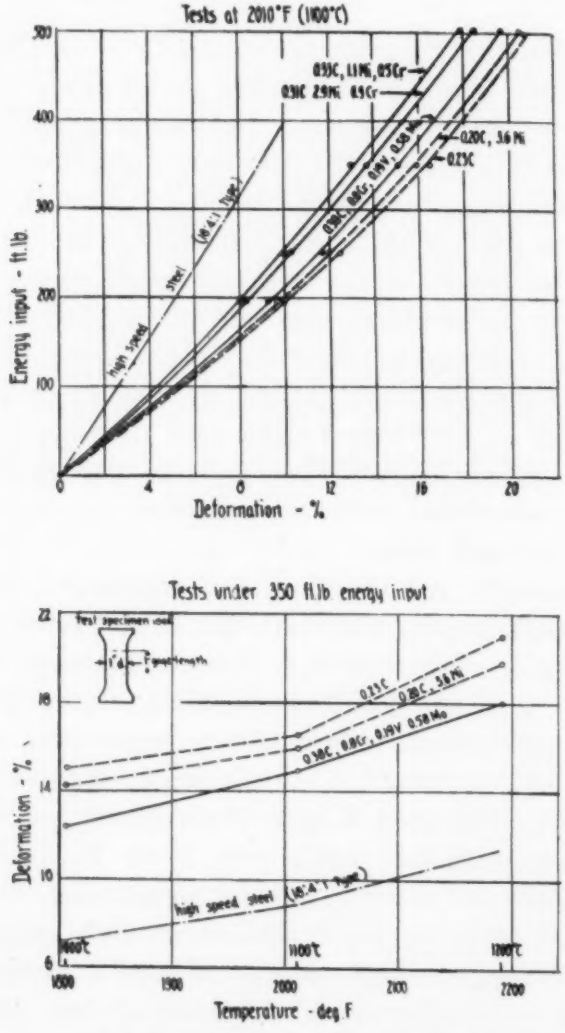


Fig. 7—Comparison of Different Steels in Single-blow Drop-tests Carried out at Hot Working Temperatures.

nickel-chromium steels, adheres more firmly to the surface of the metal. This makes it more difficult to secure well-finished bars or forgings. Thus the free-scaling properties of carbon and the chromium-molybdenum steels is sometimes a distinct advantage.

2. *Their machining properties*

Ease of machining has been one of the outstanding superiorities claimed for the chromium-molybdenum steels, but in at least one case such steels were being used in a much softer condition than the steels with which they were being compared. Under such conditions improved machining qualities can scarcely be credited solely to the type of steel.

Whether or not the chromium-molybdenum or other molybdenum steels are really better than other alloy steels from the standpoint of machining, such an impression has been created in many quarters, and it should therefore, be of interest to examine the sort of information upon which such opinions are based.

One of the main difficulties in dealing with this question is that there is no single and definite criterion of machinability. In various cutting operations, tool life, the power required to cut, the character of finish produced on the work, the permissible cutting speeds, etc., may individually or collectively be important factors in what is covered by the term machinability. Because of the complexity of the situation proponents of molybdenum steels have put their faith in production records which broadly indicate that the over-all cost of machining is less with one type of steel than with another. Study of such records as are available indicates that the percentage of saving varies not only in different operations in one plant but for similar operations in different plants.

There is, however, in published records of this sort[6] a quite clearly distinguished differential in favor of the molybdenum steels. On the other hand, it is not easy to find confirmatory test data which are based on experiments known to have been carried out under carefully controlled conditions. For example, Camp and Francis[7], report as follows:

> "Threading and turning tests, approaching uniform laboratory conditions, were made, in which it was attempted to indicate relatively the ease with which the different steels can be machined in terms of the power required to perform a definite amount of work. From the standpoint of reliable data, these experiments were disappointing, but the data obtained would indicate that the carbon steel (0.45 per cent

[6]See, for example, E. W. Pierce: Molybdenum Steel—Some Production Data. TRANSACTIONS, American Society for Steel Treating, Vol. 5, 1924, p. 571.

[7]See foot note 5.

carbon) is the easiest to machine, the chromium-molybdenum is next, and that there is little difference among the other three (1 per cent chromium, 3.5 per cent nickel, low nickel-chromium steels)."

Extensive rough turning tests using high speed steels to cut different carbon and structural alloy steels having tensile strengths

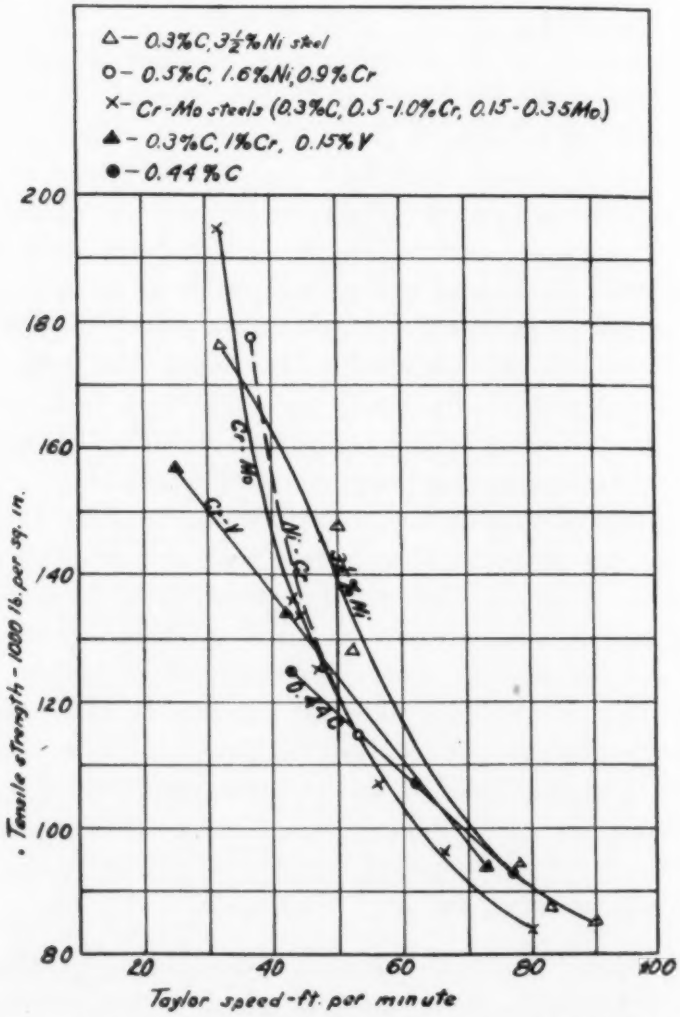


Fig. 8—Relation of Taylor Speed to Tensile Strength in Rough Turning Quenched and Tempered Alloy Structural Steels. Tests were made with ¼ inch x ½ inch Lathe Tools of 18 per cent Tungsten Type of High-speed Steel, Oil-quenched from 2400 degrees Fahr. and Tempered at 1100 degrees Fahr. Nose radius ⅛ inch; Front and Side Clearance of 6 degrees; Side Slope 14 degrees; Back Slope 8 degrees. Tests made "Dry" at 0.028 inch Feed and ⅛ inch Depth of Cut.

between about 80,000 and 190,000 pounds per square inch (160 to 400 Brinell hardness) were recently carried out by the writer and

some of his associates[8]. A summary of a small part of these tests is given in Fig. 8 and shows that when machinability can be measured, as in rough turning, by tool life (or conversely by the cutting speed) then superiority of one steel in one range of hardness or tensile strength does not necessarily mean similar superi-

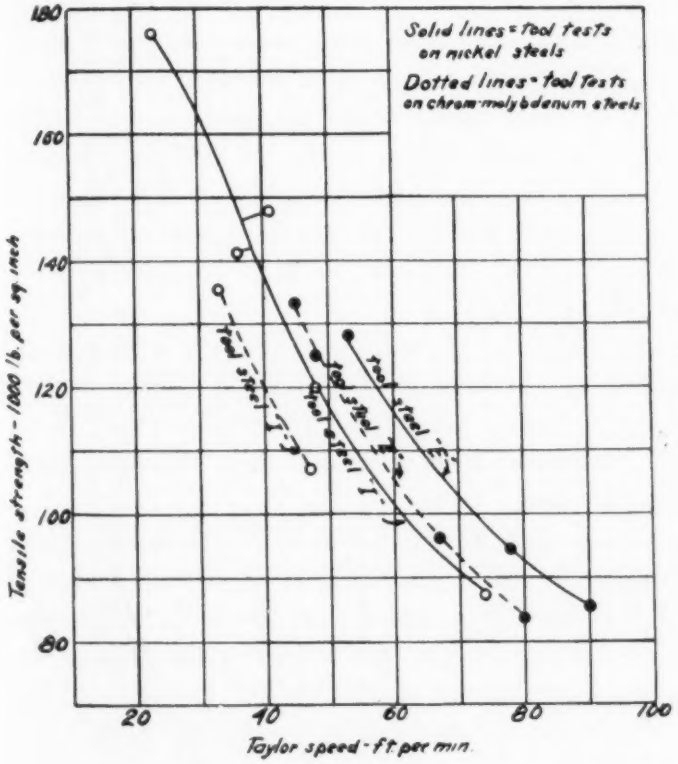


Fig. 9—Effect of Quality of Tool Steel on the Relation between Cutting Speed in Rough Turning and the Tensile Strength of the Steel Cut.

(For test conditions, refer to footnote, Fig. 8. Steels E and I are of similar chemical composition, were heat treated in the same manner but differ in performance as shown.)

ority in machinability at some very different range of hardness. Study of Fig. 8 shows that the customary chromium-molybdenum steels show superiority, only at high tensile strengths (in the neighborhood of 190,000 pounds per square inch) and in such cases the cutting speeds are practically the same as those for the nickel-chromium steels tested. At low tensile strengths, carbon steels may be said to have the best machinability, and the 3.5 per cent nickel steel the next best, but there is little difference between the

[8]H. J. French and T. G. Digges: Rough Turning with Particular Reference to the Steel Cut. Preprint of paper presented at the December, 1926, annual meeting, A. S. M. E., New York, and *Mechanical Engineering*, Vol. 49, April, 1927, pages 339-354.

1 per cent chromium, chromium-molybdenum or chromium-vanadium steels (with like carbon content).

While detectable differences are shown by these tests, it is important to note that they are no greater, in most cases, than differences which may arise from variations in the treatment and quality of the tool steels from which the tools are made. This will be apparent by comparison of Figs. 8 and 9. Tool steels E and I in Fig. 9 were purchased on the open market, and may therefore be considered to be representative of commercial products; they are almost identical in composition, as far as ordinary chemical analyses can determine, and were heat treated in the same manner, yet they show as much variation in cutting speed as arises from most of the variations in the composition of the metals cut, which variations are shown in Fig. 8.

When the finish produced on the work is important, as it is in many types of cutting, it is generally agreed that the nickel steels may more often introduce difficulties than the chromium alloy steels. However, it is probable that this difference has also been over-emphasized.

On the whole these experiments in rough turning, only a small part of which have been discussed here, lend further support to the viewpoint already expressed that there is, for many practical purposes a possibility for useful substitution among the alloying elements used in structural steels, always providing that the heat treatments and compositions are properly balanced.

3. *Their heat treatment properties*

Another feature which has frequently been emphasized is the wide hardening range of the molybdenum steels. It is of interest to note that such characteristics are by no means restricted to these particular steels. As shown in Fig. 10 quite similar effects are observed in ordinary 3.5 per cent nickel steels although the temperature range from which quenching will produce practically the same mechanical properties is perhaps not as wide as in some of the molybdenum steels.

The structural molybdenum steels have likewise been credited with higher ductility and toughness for a given strength than other commercial alloy steels for structural purposes. Whether this is so depends quite largely upon the conditions under which the comparisons are made. Under the conditions represented in Fig.

11 the molybdenum steels show to better advantage at high strengths than at low but are generally no better than the high nickel-chromium steels.

Gillett and Mack[9] quote comparisons made by the Air Service on oil-hardened steels of about 0.27 per cent carbon, one containing

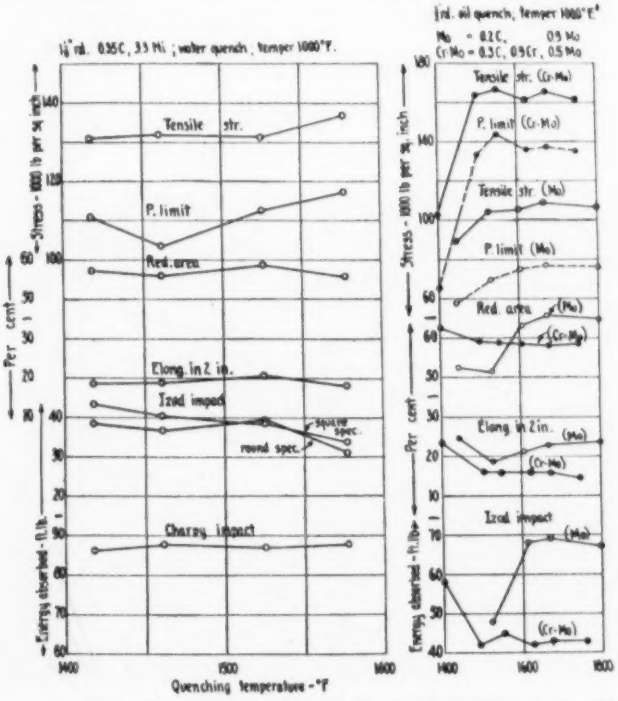


Fig. 10—Effect of Quenching Temperature on the Mechanical Properties, after Tempering, of 3½ per cent Nickel and Various Molybdenum Steels.

3.5 per cent nickel, 1.5 per cent chromium; another 1 per cent chromium, 0.17 per cent vanadium; and the third 1.2 per cent chromium, 0.70 per cent molybdenum. Their summary follows:

> "At the same draw temperatures the tensile strength of the chromium-molybdenum and chromium-vanadium were practically identical, and above that of the nickel-chromium. The nickel-chromium was consequently slightly more ductile. Of the chromium-molybdenum and the chromium-vanadium, the former showed better ductility. At Brinell hardness above 430 the chromium-molybdenum steel showed a lower proportional limit than the other two but at lower hardness the elastic ratios of the three steels were practically identical. The slight differences in torsion and in shear were mostly in favor of the chromium-molybdenum steel. The chromium-vanadium showed the lowest strength in torsion and the

[9]See foot note 4, p. 71, of reference.

chromium-molybdenum the best. Notched-bar single-blow impact tests were made both on the Izod and Charpy machines and each figure plotted is the average of four tests. Up to a 425 degrees Cent. (800 degrees Fahr.) draw there was little difference in the impact values, but at higher draw temperatures the chromium-vanadium steel gave decidedly poor re-

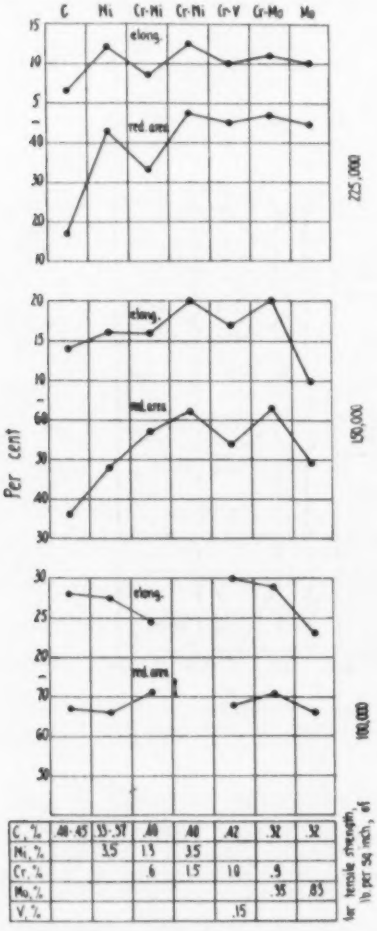


Fig. 11—Reduction of Area and Elongation of Different Structural Steels Heat Treated to show Equal Tensile Strengths.

Results taken from "Molybdenum, Cerium and Related Alloy Steels" by Gillett and Mack, The Chemical Catalogue Co., New York.

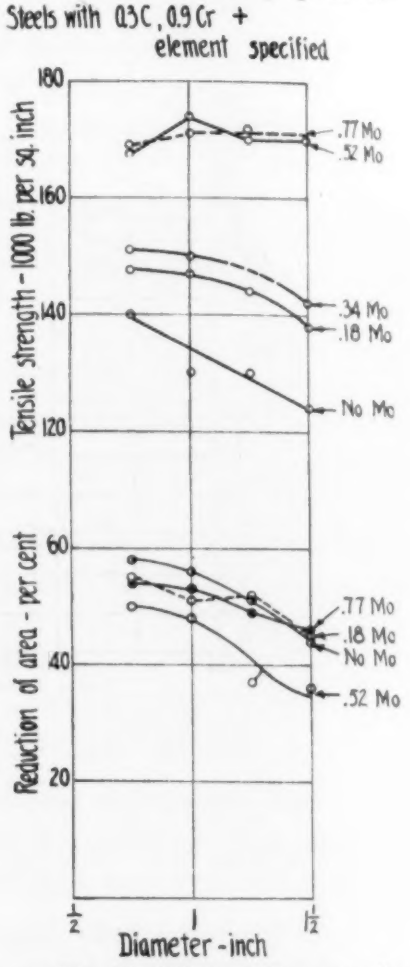


Fig. 12—Effect of Size upon the Tensile Properties of Steels Containing Various Proportions of Molybdenum (after C. H. Wills).

Refer to U. S. Patent 1,278,082. All bars Quenched from 1580 degrees Fahr. and then Tempered at 1050 degrees Fahr. Determinations made on Axial Specimens.

sults while the nickel-chromium and chromium-molybdenum were equally good. The chromium-vanadium steel gave poor results and the others good ones on both the Izod and Charpy machines.

"The depth hardening properties of nickel-chromium and

chromium-vanadium steels were compared and the nickel-chromium found decidedly superior. No figures are given for chromium-molybdenum.

"In general, these tests would indicate that the chromium-molybdenum steel was at least the equal of the other two and rather superior to the chromium-vanadium steel on notched bar impact test."

The statements as to interchangeability with respect to mechanical properties of the alloy structural steels which has been emphasized in the preceding discussion have so far been supported

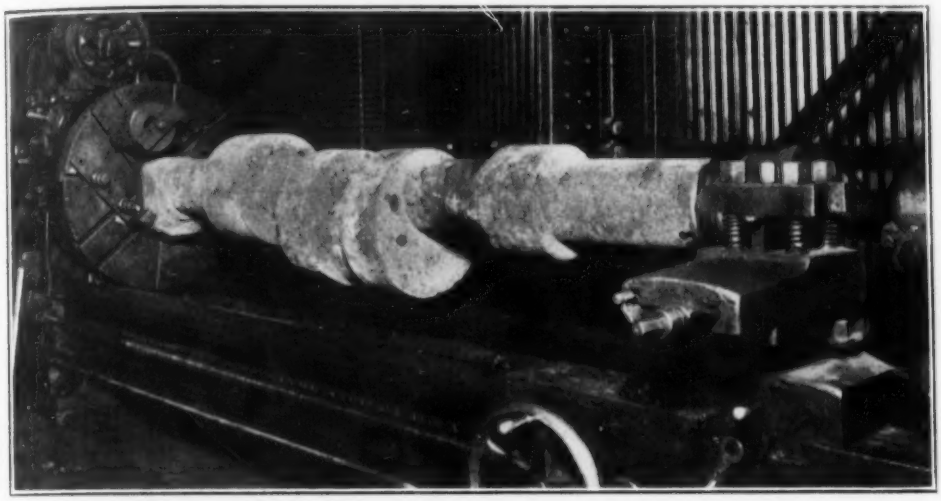


Fig. 13—Large Nickel-Chromium-Molybdenum Steel Crankshaft. Type Composition: 0.33% Carbon, 0.75% Chromium, 1.5% Nickel, 0.26% Molybdenum. Shown in Rough-machined and Heat Treated Condition. Overall length, 10 feet, 7¾ inches; Maximum diameter, 21⅞ inches; Diameter of pin, 13 inches; Diameter of arms, 10½ inches. Forged from 30-inch Ingot. Weight as Forged, 5475 pounds; as Rough-machined and Heat Treated, 3850 pounds. Manufactured by A. Finkl & Sons Co., Chicago. (Courtesy of Climax Molybdenum Company.)

only by tests on small sections. Interchangeability is somewhat more limited when one deals with larger masses. Where deep hardening properties are desired combinations of chromium and nickel or chromium and molybdenum offer advantages.

As is well known, molybdenum is exceedingly powerful in producing what may be called "air hardening propensity," and is not only superior in this respect to the three other elements under discussion, but is more effective in small amounts than equally small additions of any of the elements now ordinarily added to steels. This was brought out in Wills' patent on molybdenum steels[10] and some of the figures there quoted are reproduced

[10]U. S. Patent No. 1,278,082 to C. H. Wills.

in Fig. 12. Even 0.2 per cent molybdenum added to steel containing 1 per cent chromium is sufficient to noticeably diminish the reduction in tensile strength accompanying an increase in diameter from ¾ to 1½ inches.

In this connection it is interesting to point out a few practical applications where molybdenum is used together with other elements in steels intended for use in very large sections. One of the

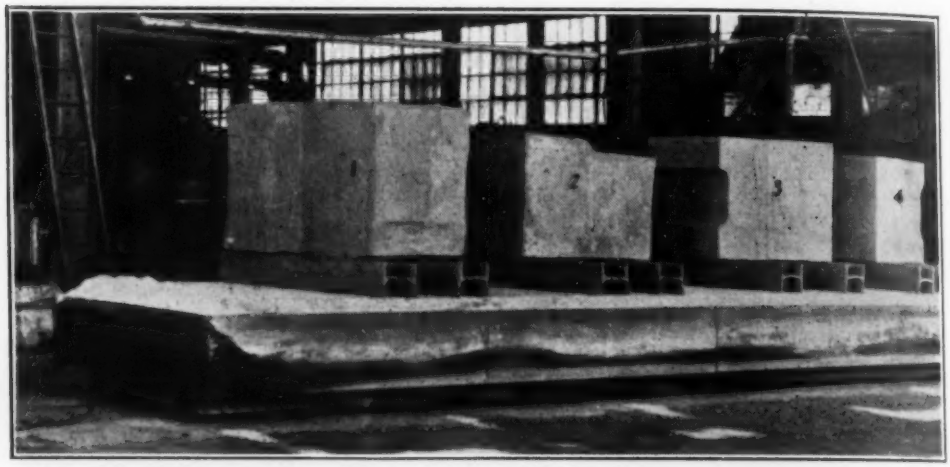


Fig. 14—Nickel-Chromium-Molybdenum Steel Rams for Steam Drop-hammers. Type Composition: 0.55% Carbon, 0.75% Chromium, 1.5% Nickel, 0.20% Molybdenum. No. 1—Rough, Weight 12,000 pounds; No. 2—Another view of same size Ram as No. 1; No. 3—Semi-finished, weight 10,000 pounds; No. 4—Another View of same size Ram as No. 3. Manufactured by A. Finkl & Sons Co., Chicago. (Courtesy of Climax Molybdenum Co.)

popular types contains about 0.75 per cent chromium, 1.5 per cent nickel, and carbon and molybdenum contents to suit the specific applications. The heavy crankshaft shown in Fig. 13 is made from Nickel-Chromium-Molybdenum steel containing about 0.35 per cent carbon and 0.20 per cent molybdenum in addition to the amounts of nickel and chromium already stated.

A similar steel, with somewhat higher carbon, (around 0.55 per cent), is used in rams for steam drop hammers, including the large sizes shown in Fig. 14. For die blocks this type of steel is modified by increasing the molybdenum to about 0.75 per cent. With such a composition it is not difficult to produce high hardness combined with toughness throughout heavy sections. An exceedingly interesting example of this is shown in Fig. 15 in the Brinell hardness values across the section of a split 6x6 inch die block, air hardened and tempered.

While these examples might suffice to indicate a thorough

appreciation among steel makers and users of the depth-hardening properties of the alloy steels containing molybdenum, it will probably be somewhat more impressive to call attention to the

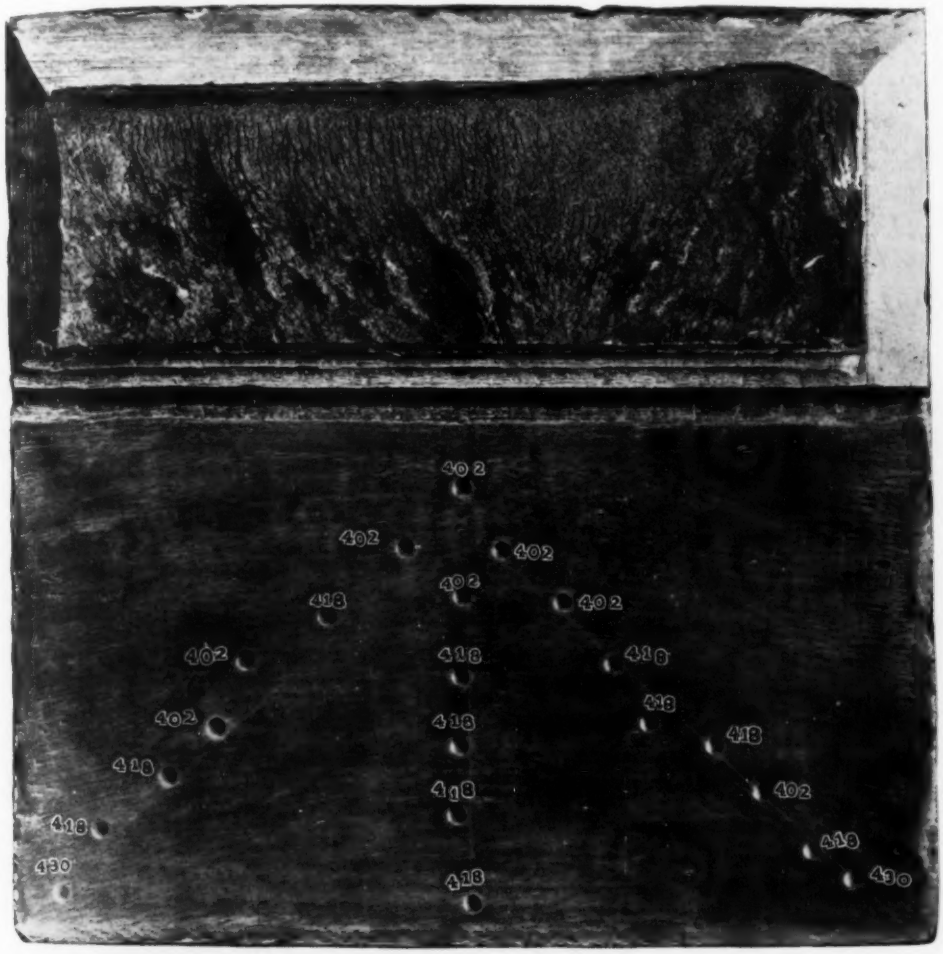


Fig. 15—Nickel-Chromium-Molybdenum Steel Die Block, Split in half to show Hardness across the Section. "Durodi" block manufactured by A. Finkl & Sons Co., Chicago. (Courtesy Climax Molybdenum Co.) 6x6x6-inch Block Air Hardened from 1600 degrees Fahr., Tempered at 1000 degrees Fahr. Steel of the Type 0.55% Carbon, 0.75% Chromium, 1.5% Nickel, 0.75% Molybdenum. Brinell Hardness Values are Stamped next to the Impressions.

large forged stock blooms from which such dies, crankshafts, hammer rams etc., are made. Two of these, each weighing about 27 tons are shown in Fig. 16.

Another of the practically useful and metallurgically interesting characteristics produced in structural steels by molybdenum is resistance to tempering. This is evidenced in Fig. 17. With sufficient molybdenum, alone or in combination with other special

elements, there is a tendency for the steel to maintain a high Brinell hardness when tempered at fairly high temperatures subsequent to hardening but when the drop in hardness does come, it is more abrupt than in the other steels. It is therefore important to select such a composition that the desired hardness is not within

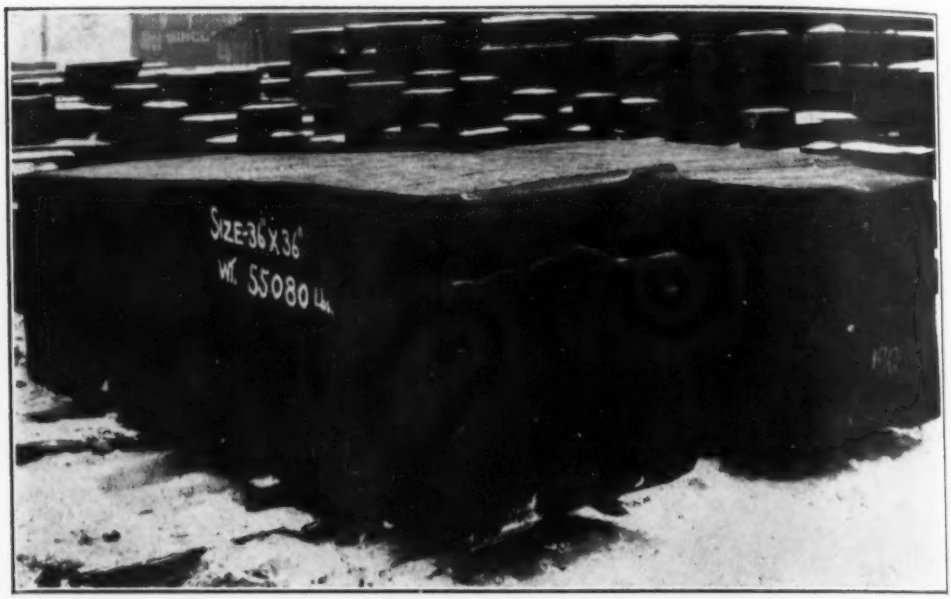


Fig. 16—Large Forged Stock Blooms from which such Large Dies, Hammer-rams, and Crankshafts as are shown in Figs. 13, 14 and 15 are made. Forged from 64-inch Ingots Weighing 165,000 pounds. Type Steel is 0.55% Carbon, 0.75% Chromium, 1.5% Nickel, 0.20% Molybdenum. Steels in background all Forged and Heat Treated Nickel-Chromium-Molybdenum Die Blocks. Manufactured by A. Finkl & Sons Co., Chicago. (Courtesy of Climax Molybdenum Co.)

this range of rapid drop as otherwise it will be impracticable to secure the desired consistency in results. This, of course, applies to any alloy steel but is perhaps more marked with the molybdenum alloy steels than with the other types.

4. *Welding, cold working and carburizing properties*

Space limitations do not permit discussion of a variety of other important properties, but brief consideration may be given to industrial practice with respect to welding, cold working, and carburizing chromium, nickel, vanadium and molybdenum steels.

While any of the customary types (such as 3 per cent nickel, 1 per cent chromium, chromium-vanadium, chromium-molybdenum steels) can be welded or brazed, the nickel steels are not good welding steels, and the chromium-molybdenum and chromium-van-

adium types have found greater favor in aircraft work where welding properties are important.

According to Johnson[11] mechanical tubing made of chromium-molybdenum steel containing about 0.25 per cent carbon, 0.9 per cent chromium, and 0.3 per cent molybdenum has several advan-

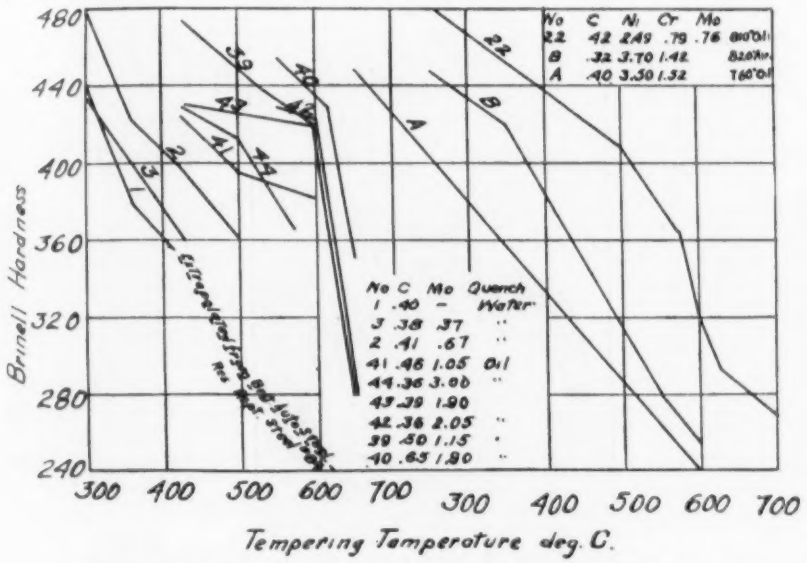


Fig. 17—Change in Brinell Hardness of Molybdenum Steels with increase in Tempering Temperature (after Gillett and Mack).

tages over such tubing made from other types of steel. It can be welded to chromium-vanadium steel sheets of customary composition and the assembly heat treated as one unit, because the hardening temperatures of the two steels are about the same; it welds easily and without the cracking which sometimes characterizes nickel steel, and it can be drawn to larger diameter and thinner walls than nickel or chromium-vanadium steel. Welding does not reduce the tensile strength below 95,000 pounds per square inch.

The nickel steels have been used widely for case hardened parts; the two important types contain respectively about 3 per cent and 5 per cent nickel, the latter having found favor where a strong and tough core with attendant resistance to crushing of the case was needed. Some metallurgists favor vanadium steels for case hardened parts above either nickel or nickel-chromium steels, but the chromium-molybdenum steels have been found to be unsatisfactory. It was claimed that grain refinement could not be obtained by a single treatment after carburization, that in the

[11] J. B. Johnson: Relationship of Metallurgy to the Development of Aircraft, TRANSACTIONS, American Society for Steel Treating, Vol. 9, No. 4, April, 1926, p. 517.

double treatment core-toughness was too easily reduced by comparatively small variations in the time of the second heating for refinement of the case and that exceedingly high hardening temperatures were required. On the other hand, nickel-molybdenum

Fig. 18—Typical Roller Bearings made from Nickel-Molybdenum Carburizing Steel. (Courtesy International Nickel Co.)

steel containing about 0.15 per cent carbon, 1.75 per cent nickel, and 0.2 per cent molybdenum is now apparently a real competitor of the customary nickel-chromium case hardening steels. It is widely used in the manufacture of roller bearings such as are shown in Fig. 18 and for other parts.

V. High Alloy Content Steels Containing Nickel, Chromium, Molybdenum or Vanadium

As already pointed out molybdenum and vanadium have not been used in large proportions in commercial structural steels. Both are, however, of value as additions along with large amounts of chromium and nickel, and both have been found experimentally to give promise of conferring useful properties on iron alloys when added in large amounts. Two recent examples which may be cited are the low carbon iron-molybdenum alloy, containing about 22 per cent molybdenum (which is reported by Sykes as giving from 30 to 50 times the life of the customary high speed steels

used for swaging dies for tungsten)[12], and a high carbon iron-vanadium alloy. This was about as good as the best work-hardened chromium steel for use as Brinell balls in testing very hard steels[13].

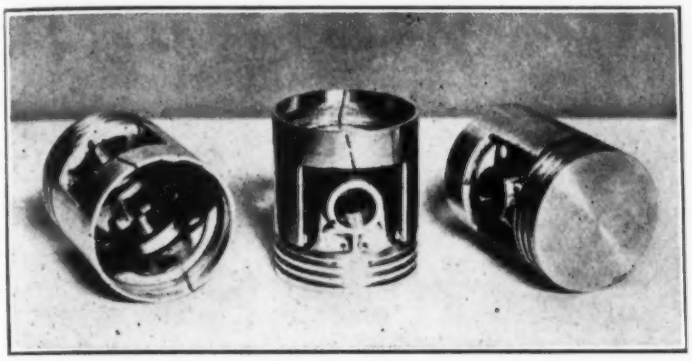


Fig. 19—"Low-expansion" Aluminum Alloy Pistons for Internal Combustion Engines. The "Strut" or Insert is of high Nickel Steel of low Expasivity. (Courtesy of International Nickel Co.)

From the industrial viewpoint, however, nickel and chromium are of much greater interest for high alloy content structural steels than the two other elements.

1. *For resisting corrosion*[14]

The commercial nickel steels are of some interest from the standpoint of resistance to corrosion. Those containing about 5 per cent of nickel, which are similar to steels used for case-hardened parts in the automotive industry, better resist embrittlement caused by caustic fusions than ordinary structural steels. Steels containing from about 25 to 38 per cent, or even more, of nickel, 0.5 per cent or less of carbon, and in some cases additions of other elements, are more resistant than ordinary steels to atmospheric corrosion and to fresh and salt waters. Some such steels have been used for valve stems in salt water lines and in boiler tubes. As a group they have better resistance than plain carbon steels to dilute sulphuric or hydrocholoric acids. Steels of this group are, perhaps, now of interest mainly for their low coefficients of thermal expansion which may, within limits, be controlled by proper adjustment of

[12]W. P. Sykes: The Iron-Molybdenum System, TRANSACTIONS, American Society for Steel Treating, Vol. 10, No. 6, December, 1926, page 839.

[13]G. W. Quick and L. Jordan: Iron-Carbon-Vanadium Alloy for Brinell Balls. Preprint of paper presented at Winter Sectional Meeting of American Society for Steel Treating, January 21, 1927, Washington.

[14]For the most part abstracted from a paper by H. J. French: Metals to Resist Corrosion or High Temperatures. October, 1926, Meeting, American Electrochemical Society at Washington.

composition. On this account they have been suggested for enamel-coated products, to cut down spalling of the coating on heating and cooling, due to differences in expansivity between the enamel and

Table III

High Alloy-Content Steels of Interest for Resistance to Corrosion

Group	Typical Chemical Composition, Per Cent							
	C	Cr	Ni	Si	Cu	W	Mo	V
High chromium steels	0.45	9.5	....	....	....	...	....	....
	<0.12	13.0	....	....	....	...	....	....
	0.30	13.0	....	....	....	...	....	....
	0.35	15.0	....	....	....	...	....	....
	0.80	18.0	....	....	....	...	....	....
	1.00	23.0	....	....	....	...	....	....
	0.10	25/30	....	....	....	...	....	....
Chromium steels with copper, silicon, tungsten, or molybdenum	0.40	3.25	....	3.3	....	...	....	....
	0.30	19.0	....	2.75	....	...	....	....
	0.30	20.0	....	....	1.0	...	....	....
	0.50	8.0	....	1.5	....	...	0.75	....
	0.60	1.70	....	1.0	....	...	0.5	....
	0.30	19.0	....	2.75	....	2.5	....	....
High chromium steels with nickel and silicon	0.45	7.5	20.0	1.0	....	...	....	....
	<0.30	13.5	36.0	3.0	1.0	...	....	....
	<0.30	27.0	24.0	3.0	....	...	....	0.3
	0.35	26.0	17.0	2.5	....	...	....	....
	low	20.0	10.0	....	....	...	....	....

the metal base. Unfortunately, these steels are not always invariable in their properties with respect to repeated heating and cooling, and it is sometimes difficult to duplicate with reasonable accuracy the desired expansivity in the selected composition.

The instability of the high nickel steels is probably greater than is generally recognized. Valve stems have occasionally been found so corroded that the threads could be picked off with the thumb nail; in some cases stems have fallen apart in the valve, and were not only broken across but split longitudinally. Instances are known where valves of high nickel steel supposedly without appreciable internal stress could not be shut off after having remained open in the line for years.

One interesting application of the high nickel steels of low expansivity is shown in Fig. 19. Here the overall expansion of aluminum alloy pistons for internal combustion engines is controlled by an insert or "strut" of high nickel steel of low expansivity. For this, steels are used similar to Invar, i. e., containing about 36

per cent nickel. In a properly designed piston of this type the clearance between the piston and cylinder wall will remain practically constant from the cold to the full operating temperature of the motor.

The high chromium steels constitute a promising, and for some purposes a very valuable, group of corrosion-resistant metals.

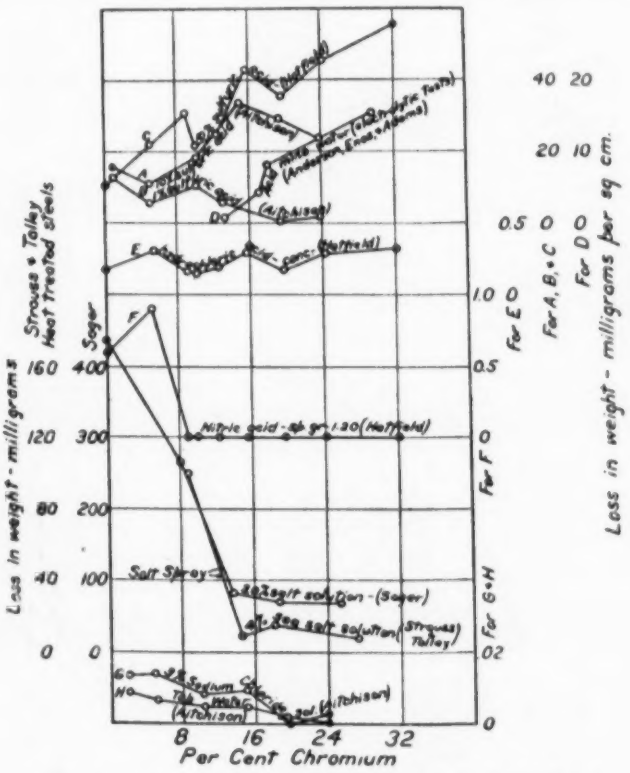


Fig. 20—Effect of Chromium on the Corrosion Resistance of Steels as Determined in Tests by various Investigators. As this chart is intended only to give a general idea of some of the effects of chromium additions to steels, the conditions of the various tests are not completely defined. Further details may be obtained from the original publications.*

However, they are costly and their stability like that of the nickel steels, has in some cases been overestimated. As shown in Table III, their chemical compositions vary widely, and include steels in which chromium alone is the special element, those containing chromium with appreciable additions of copper, silicon, tungsten, manganese or molybdenum and an important series containing high

*Aitchison, *Transactions*, Faraday Society, vol. 11, 1915, p. 212; Strauss and Talley, *Proceedings*, A. S. T. M., vol. 24, part 2, p. 33; Anderson, Enos and Adams, Bulletin No. 6, Coal-Mining Investigations, Carnegie Institute of Technology, 1923; Hatfield, *Journal*, Iron and Steel Institute, vol. 108, 1923, No. 2, p. 103; Sager, Unpublished test data obtained by T. P. Sager at the Bureau of Standards.

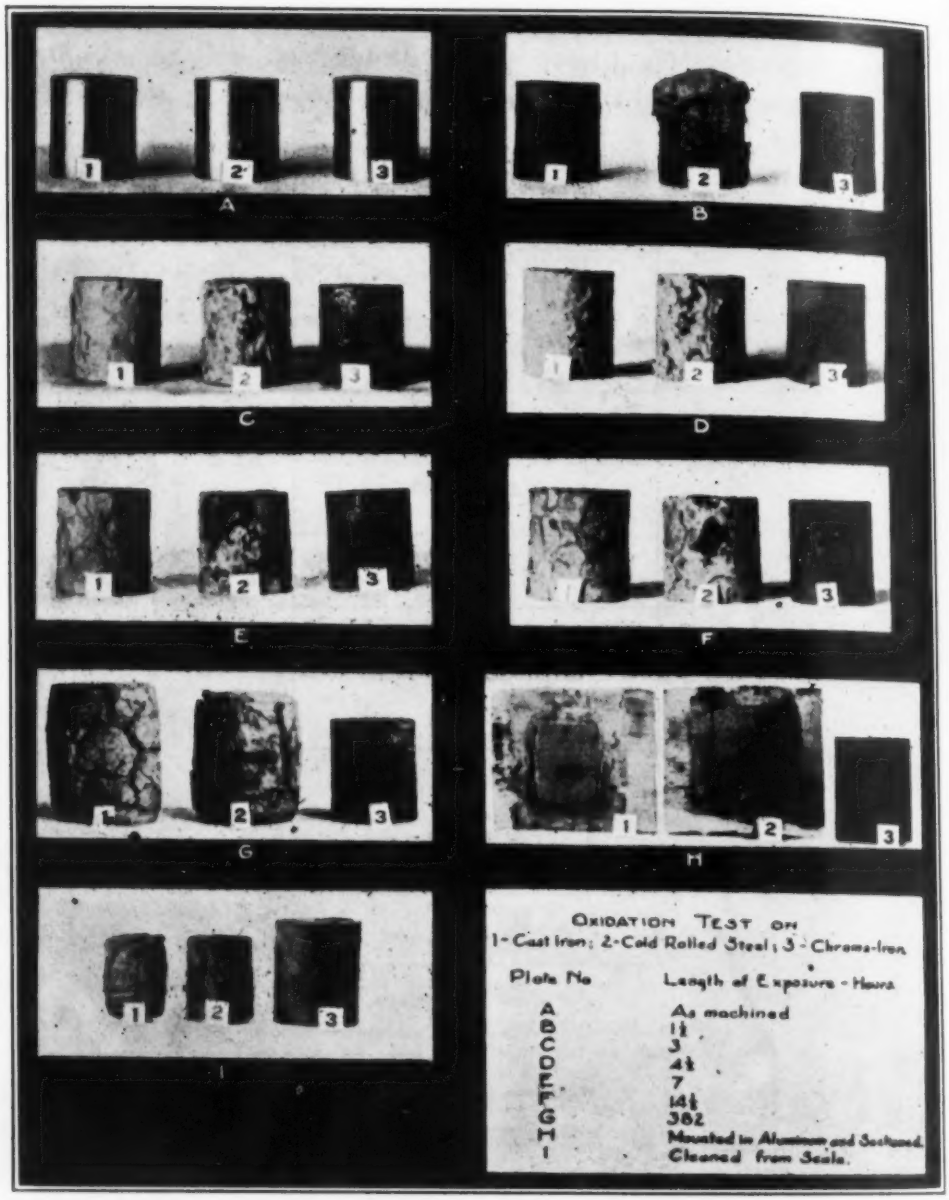


Fig. 21—Relative Oxidation at High Temperatures of Ordinary Structural Steel, Cast Iron, and "Chromium-Iron". (Courtesy of Union Carbide and Carbon Research Laboratories.)

proportions of both nickel and chromium and usually also a few per cent of silicon.

A division may be made into two groups, (1) steels which respond to heat treatment and in which a wide range in physical properties may be secured and (2) steels which do not harden appreciably when quenched and which, in general, are characterized by low elastic properties.

The first group consists largely of steels containing about 15 per cent or less of chromium, and the second of steels higher in chromium or those containing high proportions of both nickel and chromium[15].

Increase in chromium content to 20 per cent or more seems materially to improve resistance to oxidation at atmospheric and elevated temperatures, as well as resistance to fresh and sea water,

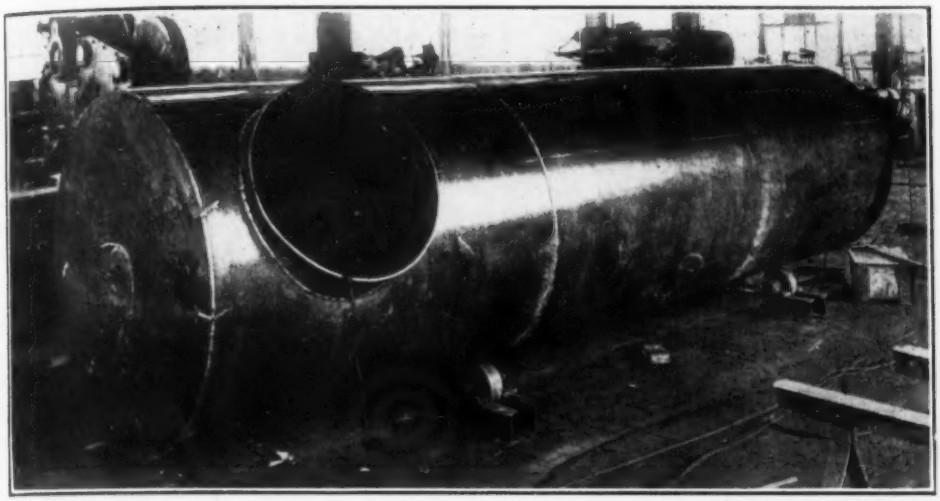


Fig. 22—A Large "Chromium-Iron" Tank used in the Chemical Industries. (Courtesy of Union Carbide and Carbon Research Laboratories.)

or to salt-air corrosion (refer to Figs. 20 and 21. While the plain chromium steels do not readily discolor in contact with fruit acids, they lose weight after long periods and are rapidly attacked by mineral acids with the exception of nitric.

To improve the acid-resisting properties, nickel is added in amounts varying from 5 to 25 per cent or more. The steels with about 25 per cent nickel are quite stable in contact with mineral acids, but are expensive and do not have the degree of malleability nor easy machining properties desirable for general manufacturing purposes. Some are, however, produced in a wide variety of forms.

Small amounts of copper, from about 0.4 to 1.5 per cent, are sometimes added to the high chromium steels to improve their acid-resisting properties, and seem to improve their resistance to oxidation and fresh and salt-water corrosion. These constitute one of the valuable groups of steels high in chromium. They are

[15]Recent researches on the constitution of these alloys are given in a paper read before the annual meeting, A. I. M. E., February, 1927, by E. C. Bain and W. E. Griffiths, entitled, "An Introduction to the Iron-Chromium-Nickel Alloys".

Table IV

Some Metals for Service at High Temperatures

TYPE	CHEMICAL COMPOSITION, PER CENT										
C Combined	Total	Mn	P	S	Si	Ni	Cr	Cu	Other Elements	Fe	Remarks
3	3	0.25	0.12 to 0.20	0.07 to 0.12	0.7	....	....	..	..	**	For annealing boxes, pots and pans.
0.7	3.4	0.7	0.20 to 0.50	0.06 to 0.10	1.5	....	....	..	..	**	For ingot molds and stools.
0.35 to 0.60	3.0 to 3.50	0.9 to 1.2	<0.35	<0.10	1.6 to 2.0	....	....	..	..	**	"Semi-steel."
	0.25	....	....	....	....	....	....	..	..	**	For steam service, in castings, wrought products, etc.
	0.3	....	....	....	....	2.5	0.7	..	..	**	For castings, steam service valves and fittings.
	0.65	....	....	....	....	1.7	0.7	..	Mo 0.7	**	For hot working dies.
	0.9	....	....	....	....	....	3.7	..	..	**	For hot working dies, moderate temperatures.
	0.2	....	....	....	....	....	2.5	..	W 8.5	**	For hot working dies, more severe service.
	0.5	....	....	....	....	....	4	..	W 10	**	For hot working dies, more severe service.
	0.4	....	....	....	3.5	....	8.25	..	..	**	For automotive engine valves.
	0.4	....	....	....	3.3	....	3.25	..	..	**	For automotive engine valves.
	0.65	....	....	....	....	....	10	..	..	**	For internal combustion engine valves, operating at fairly high temperatures.
	0.65	....	....	....	....	....	3.75	..	W 16	**	For internal combustion engine valves, operating at very high temperatures.
	1.2	....	....	....	....	....	12	..	Mo 0.7 Co 3.2	**	For internal combustion engine valves, operating at very high temperatures.
	<0.12	....	....	....	....	....	13	..	..	**	For temperatures up to about 1,475 degrees Fahr. (800 degrees Cent.). Has good resistance to scaling.
	0.3	....	....	....	....	....	13	..	..	**	Good resistance to scaling.

*Varied to meet specific requirements.

**Balance, including impurities and small amounts of elements usually present in commercial alloys.

+C + Si = 0.25 to 5.0.

NOTE: For detailed data relating to the physical properties of some of the alloys listed above, refer to the symposium on Effect of Temperature on the Properties of Metals, Proceedings, A. S. T. M., Vol. 24, pt. 2, 1924.

Table IV—(Continued)

NOTE: For detailed data relating to the physical properties of some of the alloys listed above, refer to the symposium on Effect of Temperature on the Properties of Metals, Proceedings, A. S. T. M., Vol. 24, pt. 2, 1924.

Table IV—(Continued)

TYPE	CHEMICAL COMPOSITION, PER CENT										
C Combined	C Total	Mn	P	S	Si	Ni	Cr	Cu	Other Elements	Fe	Remarks
	0.3	....	....	....	....	....	20	1	..	**	Better resistance to scaling.
	*	....	....	....	....	....	25	..	..	**	Fine resistance to scaling; not very high load-carrying ability.
	0.3	....	....	....	....	....	30	..	..	**	Fine resistance to scaling; not very high load-carrying ability.
	0.3	1	....	....	....	20	..	..	..	**	For spark points; steam service; electrical heating units (moderate service).
	1.8	....	....	....	....	5	20	..	..	**	Very good resistance to scaling.
	*	....	....	....	3.0	24	27	..	..	**	Very good resistance to scaling.
	*	....	....	....	<3.5	30 to 40	15 to 20	<1.25	..	**	Good load-carrying ability and resistance to scaling at highest temperatures, in comparison with most metals listed above.
	*	....	....	....	....	60 to 65	10 to 20	..	..	**	Good load-carrying ability and resistance to scaling at highest temperatures, in comparison with most metals listed above.
	...	....	....	....	....	85	15	..	..		For high temperature electrical service.
	...	....	....	....	....	80	20	..	..		For high temperature electrical service.
	†	....	....	....	....	94 to 99	..	..	..		For steam service, such as valve seats. The 5 per cent Mn-nickel for spark points.
	1	2	....	....	....	67	..	28	..	2	For steam service, such as valve seats; turbine construction.
	...	....	....	....	....	60	..	26	Sn 11	1.5	For steam service, such as valve seats.
	...	1.5	....	....	....	35	1 to 5	**	..	5	For steam service, such as valve seats.

*Varied to meet specific requirements.

**Balance, including impurities and small amounts of elements usually present in commercial alloys.

†C + Si = 0.25 to 5.0.

NOTE: For detailed data relating to the physical properties of some of the alloys listed above, refer to the symposium on Effect of Temperature on the Properties of Metals, *Proceedings*, A. S. T. M., Vol. 24, pt. 2, 1924.

readily machinable, require no heat treatment, have good mechanical properties, are easily fabricated, and the cost of the added copper is small. Molybdenum and tungsten are sometimes added for the same purpose but are more expensive.

Additions of manganese or silicon are primarily made to impart to these steels physical properties which favor ease of manu-

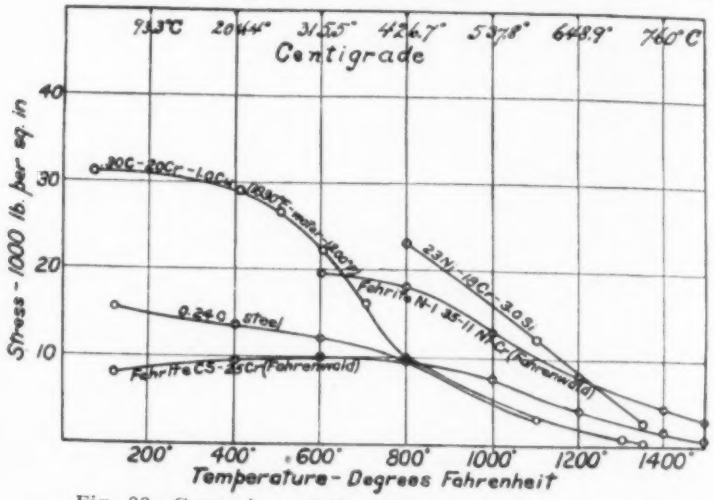


Fig. 23—Comparison of the Load-carrying Ability in Tension of Various Metals as reported by various Investigators. The several Curves Represent "Design Load Values", or so-called Maximum Allowable Stress. The Results Credited to Fahrenwald are said to be based on Actual Service Records; the remaining Curves were obtained from Laboratory Tests of long Duration by the Author. The Curve for the Steel containing 23 per cent Nickel, 18 per cent Chromium, and 3 per cent Silicon is approximate.

(For details on the origin of these data refer to footnote (14) of the text.)

facture and working. The extent to which the high chromium steels are being used cannot be indicated within the allotted space. It may be interesting, however, to call attention to the large tank shown in Fig. 22.

2. *For high temperature service*

Chromium, and to a somewhat lesser extent, nickel, play an important part in steels primarily adapted for high temperature service. Molybdenum is, as has already been pointed out, useful in some cases and gives promise of being more widely used in the future. The requirements in this field are so varied that much more space could be devoted with advantage to a discussion of parts of this subject. Merely to complete the picture which is being drawn there is listed in Table IV some of the important steels used industrially for high temperature service, together with notes concerning their outstanding properties or applications.

To further illustrate the important part played by chromium and the helpful assistance of nickel, there is given in Fig. 23 a comparison of load carrying ability at high temperatures of some of the high chromium steels with other metals; in Fig. 24, the effect of chromium and of nickel and chromium on the resistance of steels to hydrogen sulphide at high temperatures, and in Fig. 25 a summary of some experiments on the resistance to steam ero-

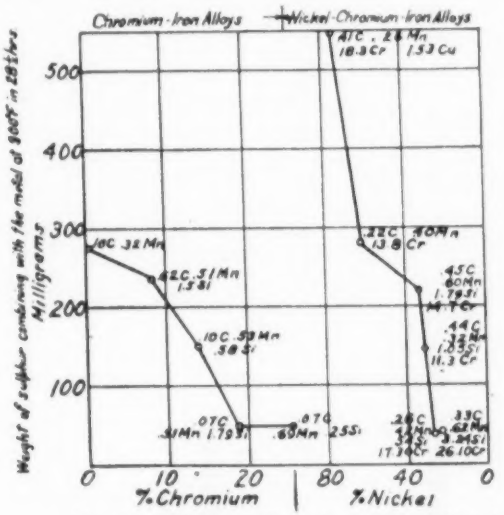


Fig. 24—Effect of Chromium and of Nickel in Iron-Chromium Alloys on their Resistance to Hydrogen Sulphide at 900 degrees Fahr. (480 degrees Cent.), as determined by Scholl.

(These results were taken from the unpublished test data obtained by W. Scholl at the Bureau of Standards. The surface area of each specimen was 8 square centimeters, exposure time 28.5 hours, gas flow 8.5 liters per hour. The amount of sulphur combined with the metal was measured by the increase of weight of the samples.)

sion of nickel and chromium steels of various types. The predominant part played by chromium in all these cases is at once evident.

Low nickel-chromium steels have for some time been used in cast steel valves in power plant service, and during the past year some forty-odd "Pacific" type locomotives similar to that shown in Fig. 26 are reported to have been built by the Canadian Pacific Railway in which 3 per cent nickel steel boiler plate was used. The operating pressure was raised from 200 to 250 pounds per square inch with the advantage, as expressed by the chief of motive power, that the new locomotives would haul one more car in a passenger train ten miles an hour faster on the same coal. These are only two illustrations, but serve to show the growing importance of alloy steels in an increasingly important field of engineering.

VI. Alloy Steels for Resisting Wear

As a final touch to the sketch which is being drawn, the subject of wear will be considered. This is taken up separately because so little co-ordinated information is available, and it is

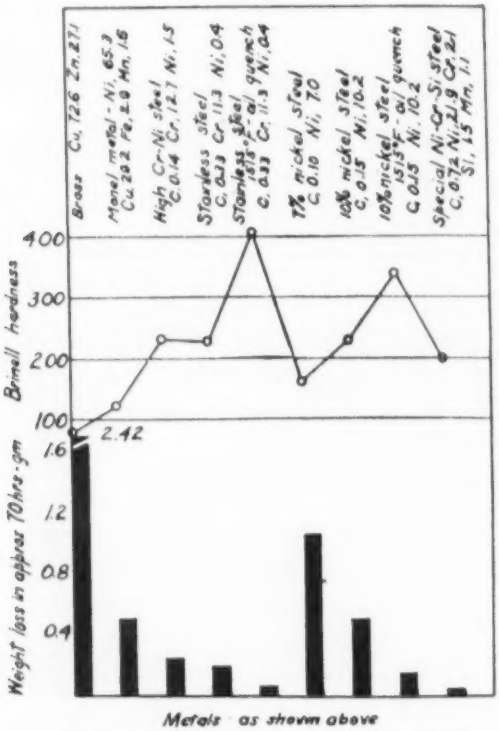

Brass Cu. 72.6 Zn. 27.1
Monel metal - Ni. 65.3 Cu. 29.2 Fe. 2.9 Mn. 1.6
High Cr-Ni steel C. 0.14 Cr. 12.7 Ni. 1.5
Stainless steel C. 0.13 Cr. 11.3 Ni. 0.4
Stainless steel 18% Cr - oil quench C. 0.33 Cr. 11.3 Ni. 0.4
1% nickel steel C. 0.10 Ni. 1.0
10% nickel steel C. 0.15 Ni. 10.2
10% nickel steel 15/35°F - oil quench C. 0.13 Ni. 10.2
Special Ni-Cr-Si steel C. 0.72 Ni. 21.9 Cr. 2.1 Si. 1.5 Mn. 1.1
Brinell hardness
400
300
200
100
2.42
Weight loss in appros 70 hrs - gm
1.6
1.2
0.8
0.4
Metals as shown above

Fig. 25—Resistance to Steam Erosion of some Common Alloys as recently Reported from Switzerland. For Details of these Experiments, refer to Corrosion et Erosion des Ailettes de Turbines a Vapeur. Brown, Boveri et Cie Revues, Vol. 11, Dec. 1924, No. 12, p. 263.

hazardous to make any very definite or general statements. In practical service, many types of wear are encountered and metals which resist one type do not necessarily resist others.

At least one of the fundamentals is recognized and that is that hardness as now ordinarily measured, and which may be defined as the resistance to permanent deformation, is no certain criterion of wear. Ordinarily wear takes place by displacement and removal of metal particles from the contact surfaces of solid bodies. High hardness promotes resistance to wear by increasing resistance to penetration or displacement; on the other hand, a high degree of toughness tends to promote resistance to wear by making difficult the detachment of particles which may have been displaced.

Since hardness and toughness both seem to contribute to the wearing properties, it may be expected that small additions of nickel, chromium and molybdenum to steels which result in better

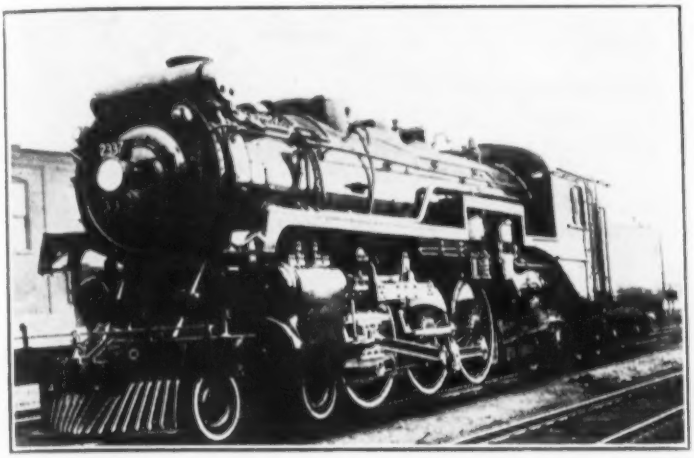


Fig. 26—One of 44 Locomotives Built in 1926 by the Canadian Pacific Railway in which 3 per cent Nickel Steel plate was used in the Boilers. (Courtesy of International Nickel Co.)

Table V

Effect of Small Additions of Special Elements, Such as Are Ordinarily Found in Commercial Structural Steels, on Wear Resistance as Determined by Different Investigators[1]

Variable	How wear resistance is affected by the variable in column 1. Abrasive Wear Tests		Unlubricated Rolling Friction	
	Robin	Brinell	Saniter	Norris
Small additions of				
Manganese ...	reduced	improved	little influence	improved
Silicon		reduced		
Nickel	reduced	improved	improved	improved
Chromium	improved	improved		improved
Tungsten	improved			
Vanadium	improved			improved

combinations of hardness and toughness than those observed in carbon steels will improve wear resistance. It will not be disputed that this is so in some cases, but the exact conditions of service to which these statements apply cannot be defined at this time.

[1]This applies only to steels in a "soft" condition, i. e., as hot finished, tempered at high temperatures subsequent to hardening, annealed or normalized. For sources of information, refer to TRANSACTIONS, A. S. S. T., Vol. 10, No. 5, November, 1926, page 683.

Merely as an example of the difficulties encountered in attempting to interpret existing wear test data, there is shown in Fig. 27 the effects of some special elements on the wear of steels

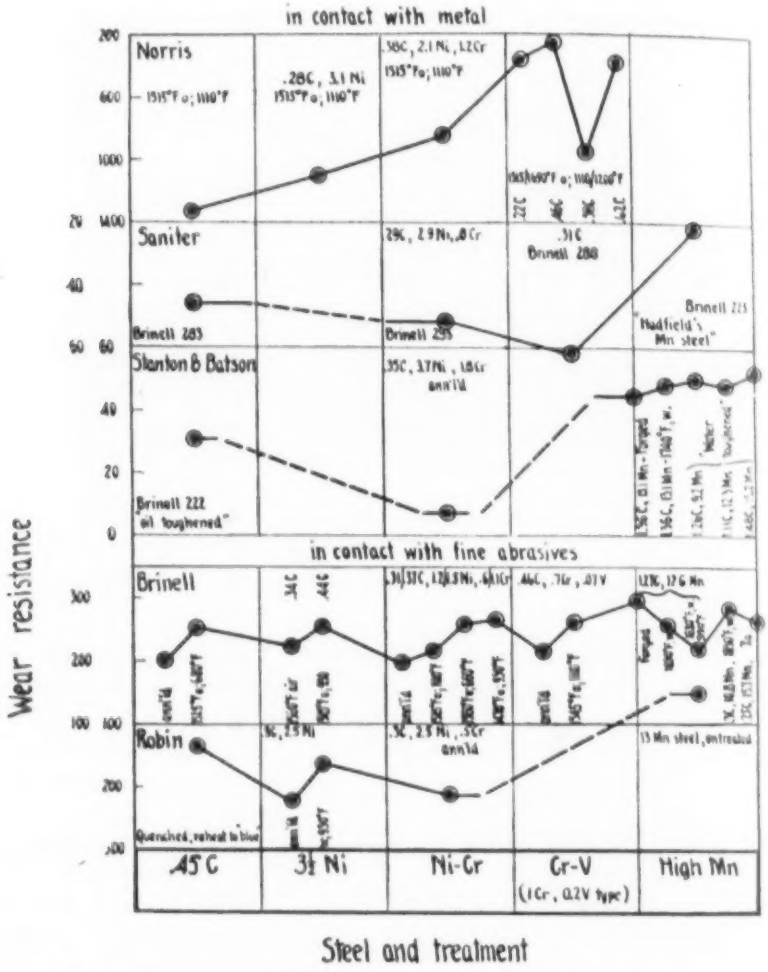


Fig. 27—Wear Resistance of various Structural Steels as determined in Laboratory Tests by different Investigators.
(For details on the origin of these data refer to TRANSACTIONS, American Society for Steel Treating, Vol. 10, Nov. 1926, No. 5, p. 683.)

as determined by different investigators; a more general summary is given in Table V. In both Fig. 27 and Table V there are notable disagreements, but the results show that at least under certain conditions, nickel and chromium additions increase the resistance of steels to wear. Convincing data are lacking for molybdenum, but there is no reason to believe that it would not also have an effect, under corresponding conditions of tests, similar to that of the other two elements. It is open to question whether vanadium, in

the small proportions ordinarily used in structural steels, has any marked effect on wear resistance.

For abrasive wear under moderate pressures, there seem to be no radical changes in wear resistance produced by additions of small amounts of the four alloying elements being discussed. This

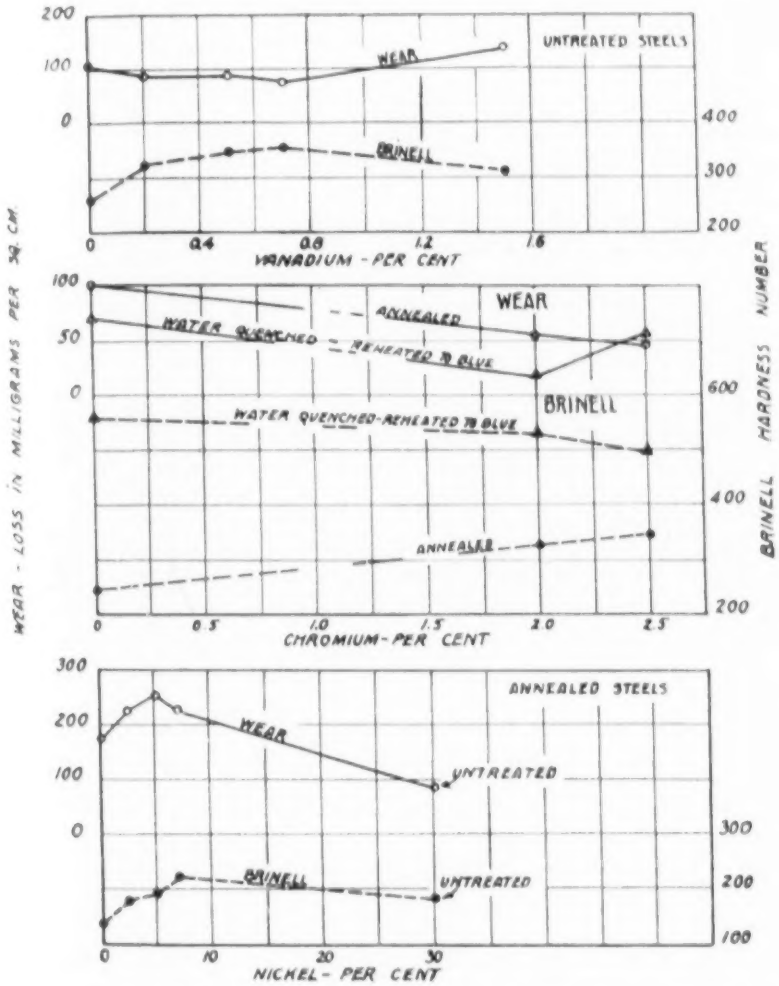


Fig. 28—Effect of Nickel, Chromium or Vanadium on the Wear of Structural Steels as Determined by Rebin.
(For details of these "Abrasive Wear" tests refer to Carnegie Scholarship Memoirs, Iron and Steel Institute, Vol. II, 1910, page 6.)

is shown in Fig. 27, and additional data for a variety of conditions are given in Fig. 28. This is obviously a field for much further work and is being studied from a number of viewpoints at the Bureau of Standards and by many industrial organizations.

Not only are experiments needed which will throw further

light upon the fundamentals of wear resistance of metals but it is also essential to tie together results of laboratory tests and practical service to the end that standardized methods of test may be evolved and improved alloys developed.

In view of the conflicting data on the effect of small proportions of nickel on the wear resistance of steels, it is interesting to note a recent application of cast low nickel-chromium steels for

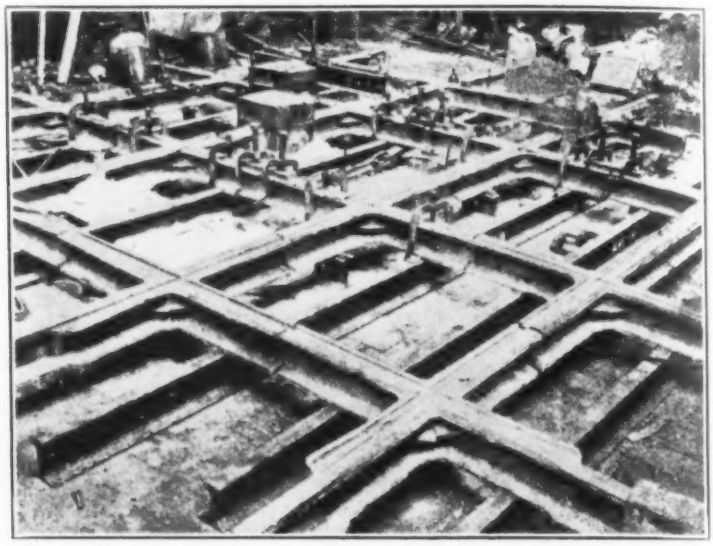


Fig. 29—Cast Nickel-Chromium Steel Street Car Track Work. For details refer to text. (Courtesy of International Nickel Co.)

railroad track work. The track shown in Fig. 29 is made of steel containing about 0.50 per cent carbon, 0.75 per cent chromium and 2.75 per cent nickel, double annealed, and shows a tensile strength of about 110,000 pounds per square inch, elongation of 17 per cent in 2 inches and 26 per cent reduction of area.

This steel has a Brinell hardness of about 219, and unlike high manganese steel, is machinable, and can be welded, worn sections being repaired by deposition of new metal. No claims are made that this is the best steel for the purpose; the example is merely cited to show an interesting application of low nickel-chromium steel for a type of service requiring wear resistance as well as other important properties.

VII. Summary

In the previous discussion an effort has been made to empha-

(Continued on Page 1000)

CORRELATION OF MAGNETIC PROPORTIES WITH MECHANICAL HARDNESS IN COLD-WORKED METALS—Part II—Nickel Strips

By S. R. Williams

Abstract

The change in length due to a magnetic field, (Joule magnetostrictive effect), the coercive force, residual magnetism, hysteresis loss per cycle and electrical conductivity are all studied in a set of nickel strips which have eleven degrees of hardness obtained by cold rolling. With all these effects measured on the same set of nickel strips it is possible to study the results with a view to correlation and with the possibility that some light may be cast upon that "hazily conceived conglomeration or aggregate of properties of a material, more or less related to each other" known as hardness.[1]

Introduction

THE modification of any physical or chemical quality of a substance is always accompanied by a corresponding change in its magnetic characteristics. An accumulation of evidence supporting this general proposition suggests that variations in hardness may be legitimately studied by magnetic methods. In the preceding section of this study[2] it was shown, that, in a series of steel rods having the same chemical constitution, the values of the maximum elongation of the steel rods in a magnetic field progressively changed with decreasing hardness. In the case of the steel rods their different degrees of hardness were obtained by special heat treatment. On the other hand, nickel obtains its various degrees of hardness by mechanical working which in the present study was done by means of cold rolling. Will the hardness thus obtained by the two methods show themselves to be common property of matter when studied from the magnetic viewpoint? This particular paper will deal with a series of eleven nickel strips which progressively have different degrees of hard-

[1] Tuckerman, *Mechanical Engineering*, January, 1925, p. 53.

[2] S. R. Williams, Transactions, American Society for Steel Treating, Vol. 5, April, 1924, p. 362.

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. The author, Dr. S. R. Williams, is professor of physics, Amherst College, Amherst, Mass.

ness. Work is also under way in a study of an equal number of cold-rolled monel metal strips. In order that the third method of hardening, viz., by alloying, might be studied a series of sixty steel rods were prepared consisting of six groups of ten each. Each group has a different carbon content from low to high carbon steels. The ten rods in each group were each given a different degree of hardness by heat treatment. Various magnetic properties were studied in the hope that out of the correlation may come additional information concerning this unknown property of hardness. The change in length due to a magnetic field, residual magnetism, coercive force and hysteresis are the main magnetic properties to be studied. Special attention was paid to the magnetic change in length because in this phenomenon we have the magnetic and the mechanical properties so closely related.

Preparation of Nickel Strips

Through the courtesy of Dr. Paul D. Merica, director of research, of the International Nickel Company a set of eleven strips of nickel was furnished for the purposes of this investigation. The strips were ¼ by 2 inches in cross-section to begin with and were successively rolled to different degrees of thickness and con-

Table I
Cold Rolled "A" Nickel Strip

Sample No.	Scleroscope Hardness (Universal tup or hammer)	Per cent Cold Reduction
1	17	0
2	27	9.7
3	31	18.9
4	35	28.9
5	40	39.5
6	43	50.0
7	45	59.5
8	47	69.0
9	50	79.0
10	51	89.1
11	49	93.3

The chemical analysis of this material is as follows:

	Per Cent
Copper	0.16
Nickel	98.88
Iron	0.56
Sulphur	0.008
Silicon	0.06
Carbon	0.09
Manganese	0.23

sequently different hardness as shown in the Table I. Fig. 1 shows the relation between the per cent of cold reduction and the scleroscope hardness. Table I gives the chemical and physical properties as supplied by Dr. W. A. Mudge, superintendent of research in the International Nickel Company.

After these strips were received in our laboratory they were carefully cut in two, lengthwise, and trimmed to a width of $\frac{3}{8}$

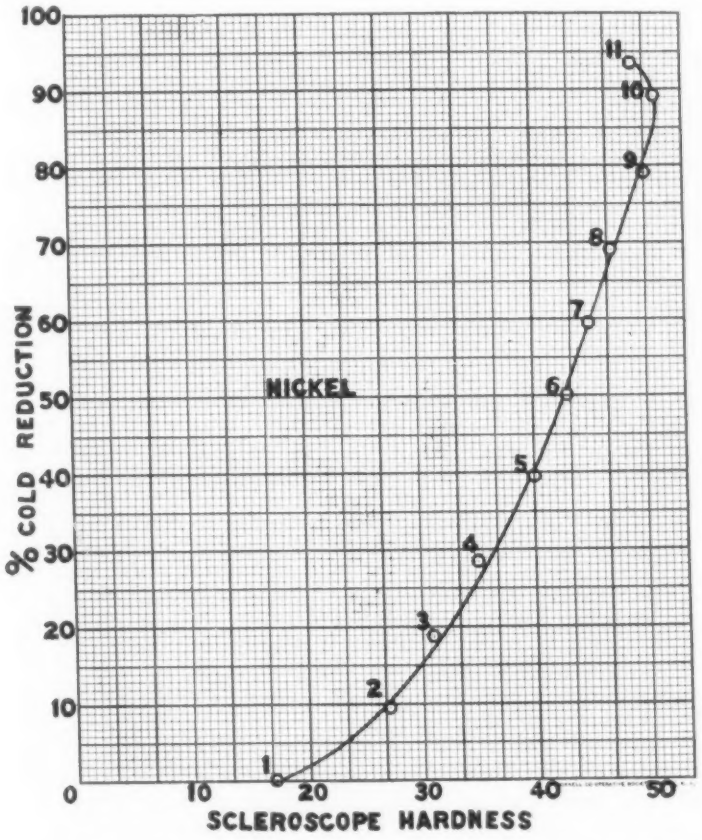


Fig. 1—A Graphical Representation of the Increase in Hardness of a Series of Eleven Nickel Strips as They are Cold-Rolled to Successively Thinner Dimensions.

inch, the thickness being that given in Table I, while all of the strips were cut to a length of 22¾ inches. This furnished two specimens from each strip so that throughout the work it was possible to run checks on the two samples from the same original strip. The two sets of strips were lettered as follows:

$A_1, A_2, A_3, A_4, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots A_{11}$

and

$B_1, B_2, B_3, B_4, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots B_{11}$

respectively in which the subscripts correspond to the sample numbers given in Table I.

In the cutting and shaping of the strips great care was taken that the temperature of the specimens should not rise more than ten or fifteen degrees in order that the mechanical properties would not be changed by any temperature effects. That the two specimens from each sample of nickel checked up with each other

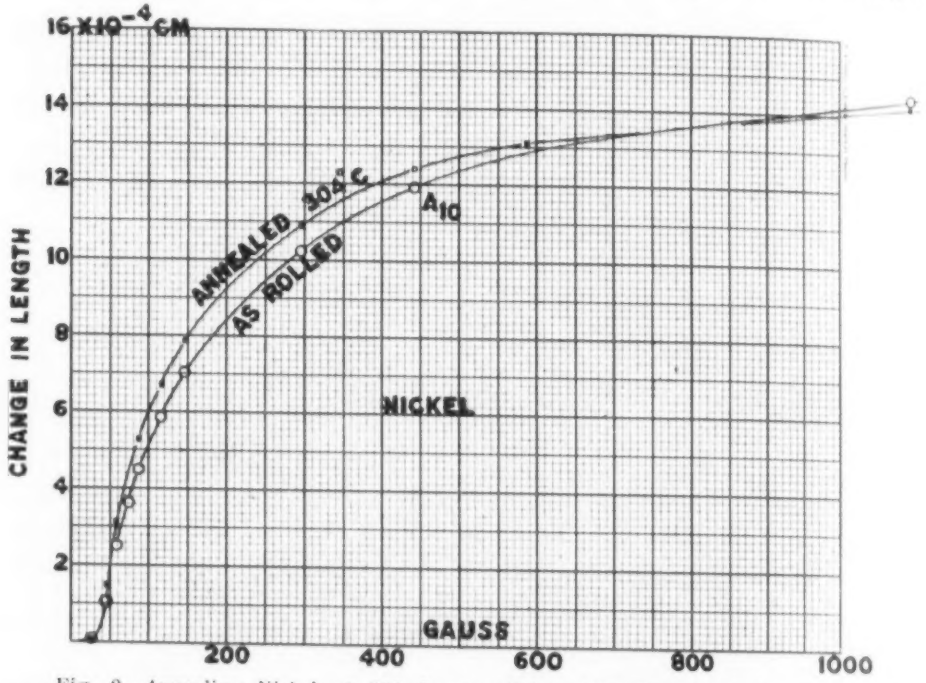


Fig. 2—Annealing Nickel at 580 Degrees Fahr. (304 Degrees Cent.) Changes the Physical Properties to Some Extent. This Shows How the Nickel Strip As Varied in Length in a Magnetic Field Before and After Annealing.

indicated that the cutting and machining processes had not affected the mechanical properties unless it had affected the two in the same manner. Furthermore it was suggested that the local strains set up in the rods should be released by heating at 570 degrees Fahr. (300 degrees Cent.) as this would not affect the mechanical properties of the rods. This was done in an oil bath of lard oil which was kept in constant motion by forced circulation of the oil from one end of the rods to the other. Changes in length due to magnetization were measured both before and after this heating process. In all of the rods there was an increase in the magnetic change in length due to this heat treatment amounting to an average increase of about 9 per cent but the increase was greatest for the thinner rods, i. e., those having the greatest

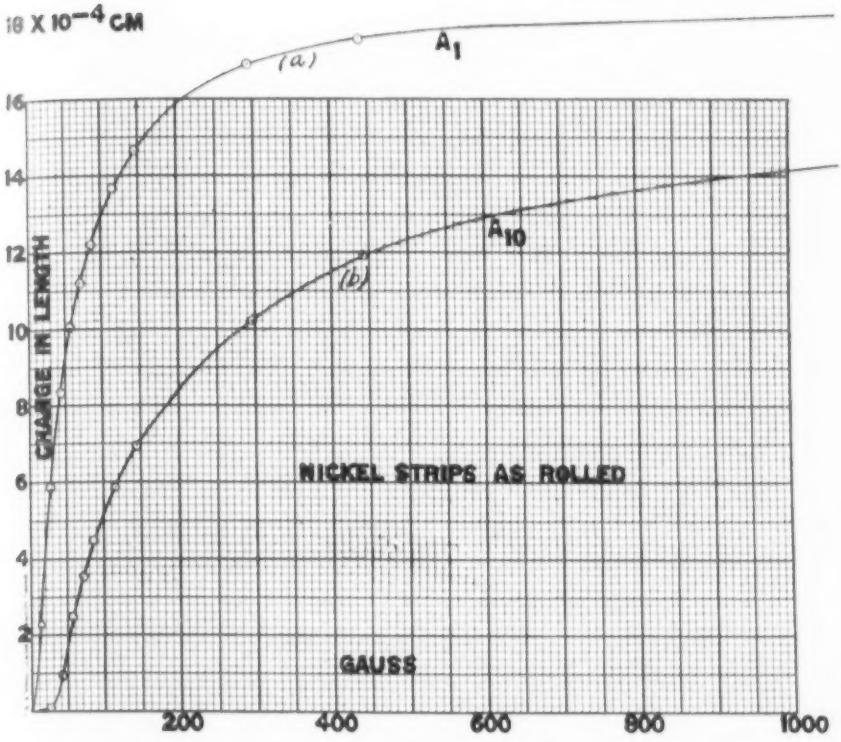


Fig. 3—The Change in Length in a Magnetic Field was Measured for All the Magnetic Strips. This Indicates the Change in Length of the Strips A_1 and A_{10} Before Annealing.

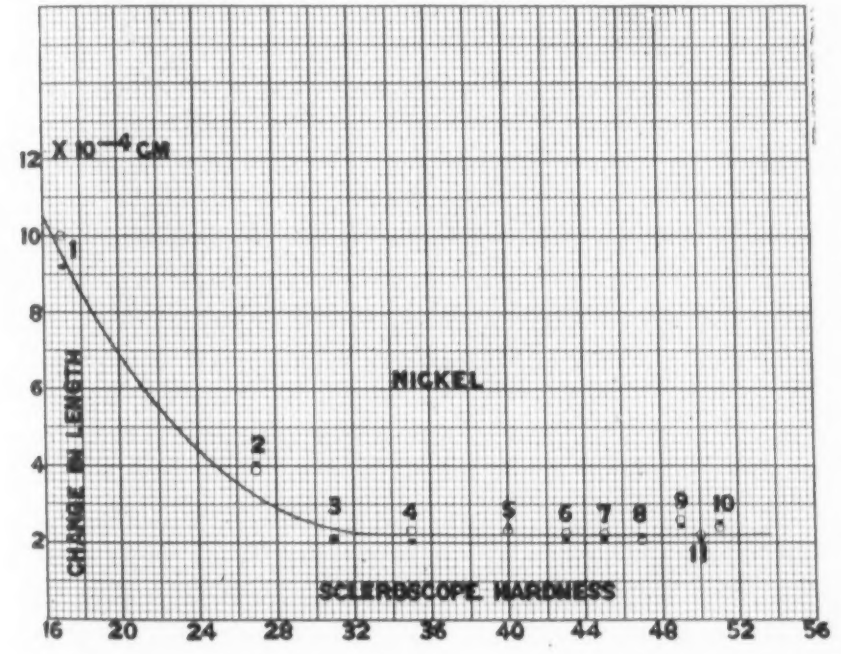


Fig. 4—At a Field Strength of 58.8 Gauss the Change in Length Due to Such a Magnetizing Force Acting on the Various Nickel Strips is Compared with the Scleroscope Numbers. Circles Denote Readings for the A Series of Strips and the Square Dots are Those for the B Series.

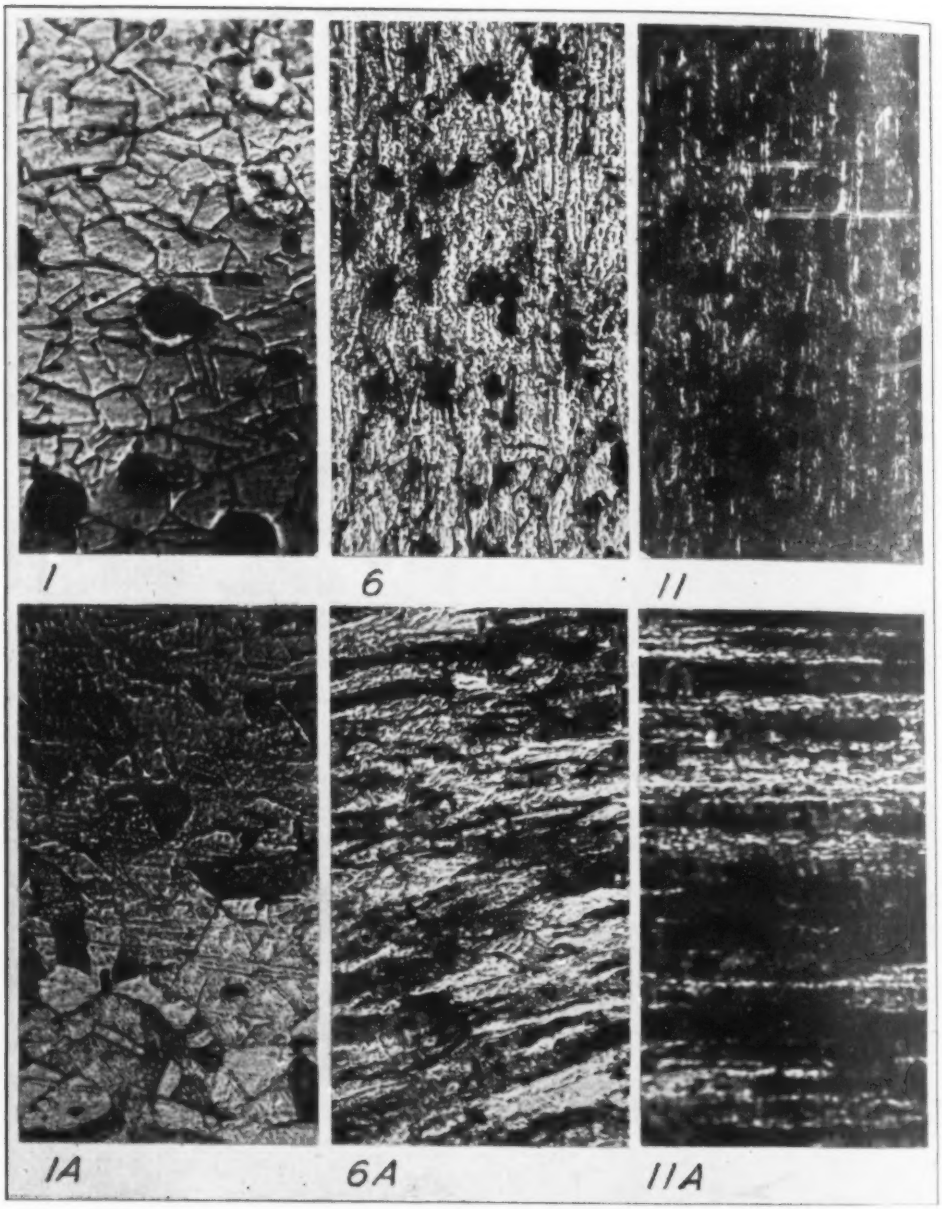


Fig. 5—The Microstructure of the Nickel Strips Show That Successive Rollings Decreased the Size of the Non-Magnetic Portions and Consequently the Size of the Crystals. The Photomicrographs Shown are for Strips 1, 6 and 11 Only and Were Made from Sections Cut from Original Pieces Sent from the Factory.

amount of rolling. The way in which this change in the Joule effect occurred is shown in Fig. 2. The greatest percentage increase of length occurred at a field strength of between 75 and 125 gauss, actually decreasing beyond 800 gauss. The annealing of these strips at 580 degrees Fahr. (304 degrees Cent.) for an

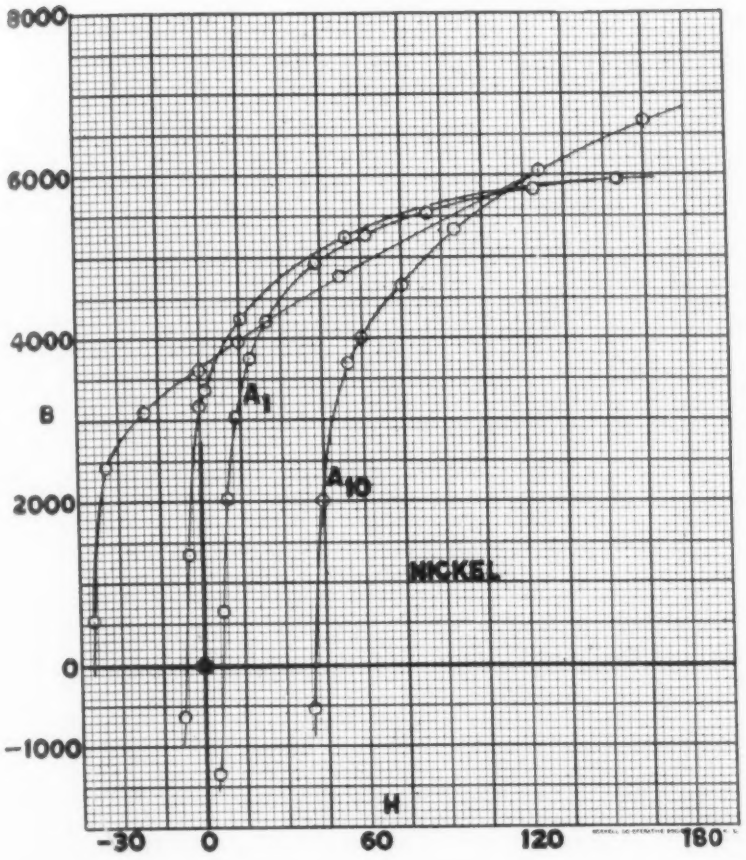


Fig. 6—Hysteresis Loop Areas for the Nickel Strips A_1 and A_{10}. These Two Specimens Gave the Extremes of Areas. A_{10} Shows Five Times as Much Hysteresis Loss as A_1.

hour, however, seemed to give greater consistency in the readings of the magnetic changes in length.

Experimental Data

The device for measuring the changes in length of the nickel rods when placed in a magnetic field has been described elsewhere.[3] It was possible to detect a change in length equal to 1/25 of a wave-length of sodium light.

In Fig. 3 is shown the way in which the change in length per unit length of the rods occurred as the magnetizing force was varied from zero upward to a value of about 12-1300 gauss. Curve (a) is for the rod A_1 while (b) is the curve for A_{10}. The curves for the other rods lie between these two and bunch to-

[3] Williams, J. O. S. A., 7, p. 1011, 1923.

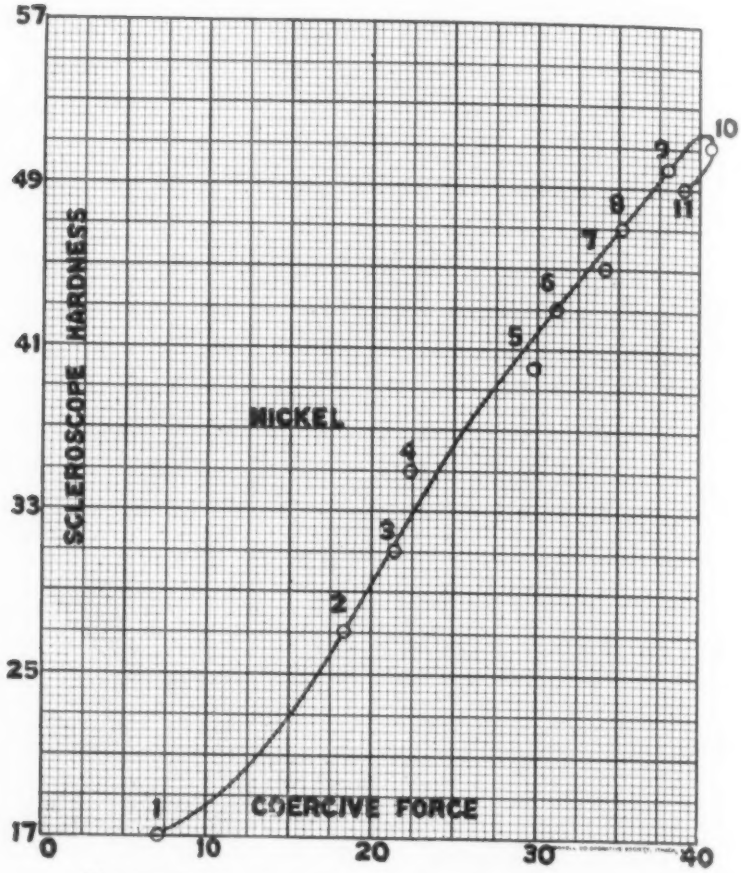


Fig. 7—From the Readings for Hysteresis Loop Areas, the Values for the Coercive Forces in the Various Strips Were Determined. This Figure Shows this Relation Graphically.

gether nearest the curve (b). Rod A_{10} was selected in preference to A_{11} because it showed the highest hardness number. In measuring the changes in length, the solenoid producing the field was set in a vertical position. This meant that the rods were parallel to the vertical component of the earth's magnetic field. This was eliminated by the use of an auxiliary coil inside of the solenoid, through which a direct current flowed giving a vertical field just equal and opposite to the vertical component of the earth's field. When all of the extraneous fields were removed or equalized, not one of the rods showed any lengthening as Heydweiler[4] found, but the change in length was a shortening for all field strengths. Nickel is particularly sensitive to extraneous magnetic fields, but inasmuch as there were eleven conditions of the nickel it seems

[4]Heydweiler, Ann. d. Physik., 15, p. 415, 1904. Phys. Zeitschr., 5, p. 255, 1904.

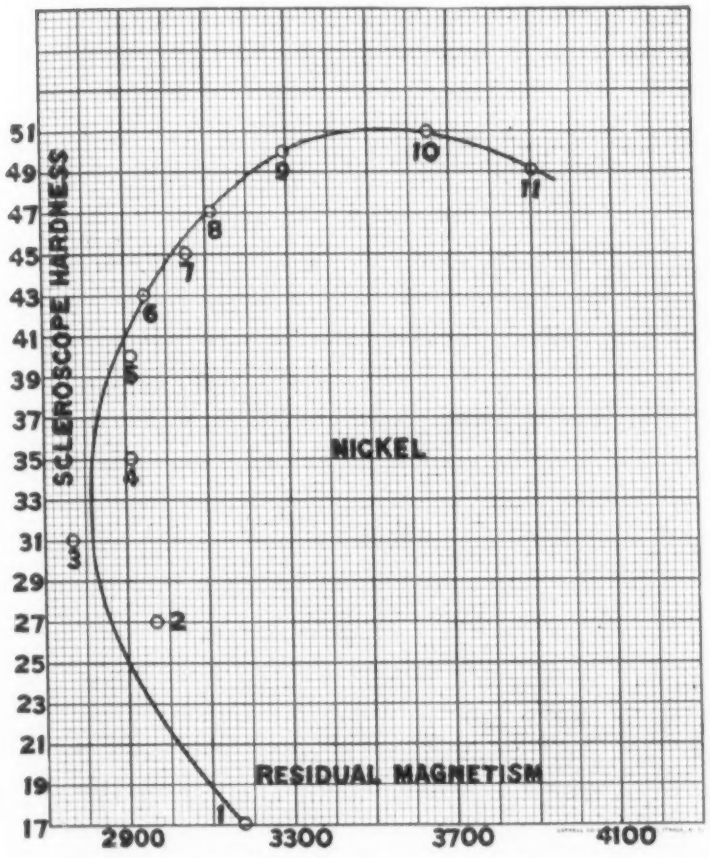


Fig. 8—In the Case of Steel the Residual Magnetism is Largely a Function of Hardness. This Curve Shows that Nickel Also Possesses a Variation of Residual Magnetism with Hardness.

rather conclusive that nickel does not show a lengthening for small magnetizing forces as is the case for iron.

In order to compare the changes in length with hardness values, a definite magnetizing force was selected and the values of the change in length for the different rods at this particular field strength were plotted against their corresponding hardness numbers. This is shown in Fig. 4. It will be seen that after a certain degree of reduction in thickness has been accomplished the change in length becomes asymptotic with the axis of hardness. This seems to indicate that, whatever the machinery is whereby the change in length is brought about, the process of rolling has by the end of the third reduction in thickness reduced that machinery to the same phase and thereafter the change in length remains the same and this holds true for all of the field strengths studied in this paper. In Fig. 4 the field strength

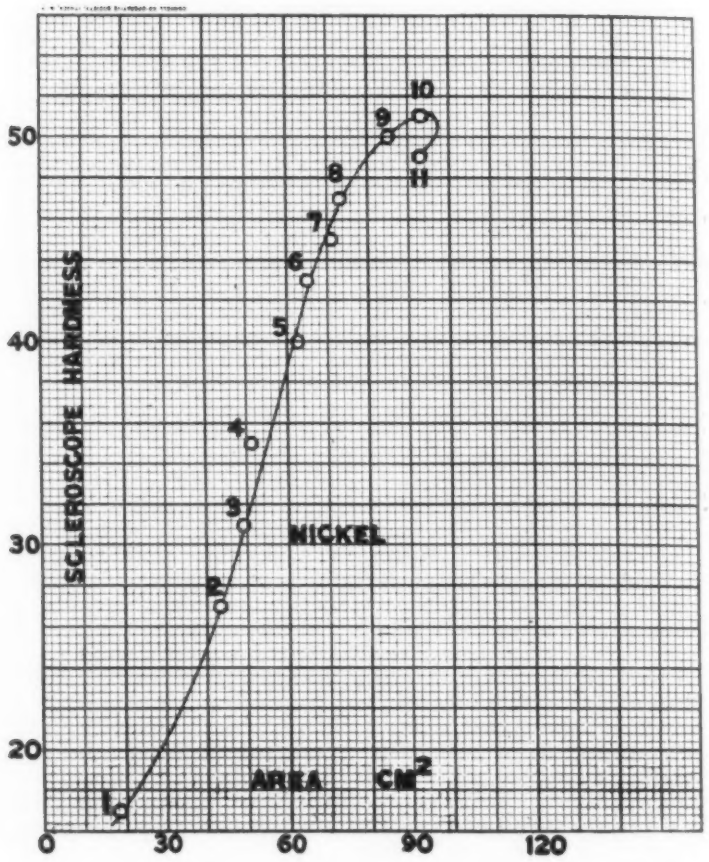


Fig. 9—Hysteresis Curves were Obtained for All of the Nickel Strips. Areas Plotted in this Figure are the Readings of the Planimeter in Square Centimeters. These Areas Should be Multiplied by the Factor 598 to Give Ergs per Cubic Centimeter.

chosen for the comparison was 58.8 gauss, (0.4 amperes in the solenoid).

A study of the photomicrographs of the nickel rods in their various stages of rolling and hardness was of interest in connection with the changes in length which occurred. These are shown in Fig. 5. The numbers under the photomicrographs correspond to the number of the sample as given in Table I. The plain number indicates a photomicrograph taken as though the rod were cut in two and a photomicrograph taken of the end, i. e., normal to the direction of rolling. The photomicrographs numbered by letter and number indicate those taken along the edge of the strip parallel to the direction of rolling. The samples in each case were ground, polished with levigated alumina and etched approximately two minutes with concentrated nitric acid. The pictures

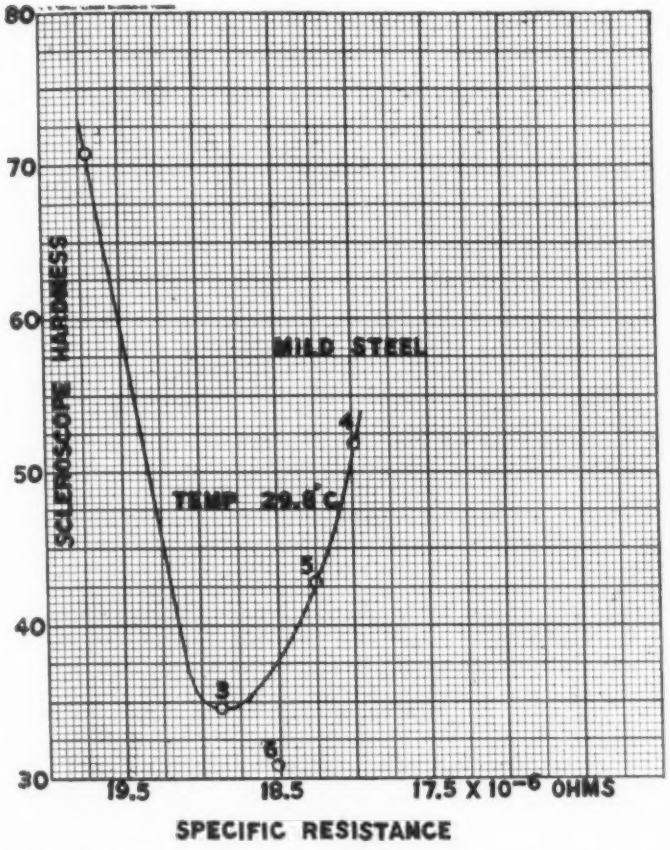


Fig. 10—The Specific Resistance of Five Mild Steel Rods are Herewith Compared with Their Hardness. Rod No. 6 Does Not Fit Into the Curve Because It was Annealed for Two Hours and the Others for Only Fifteen Minutes.

were taken at a magnification of 250 diameters, through a green filter. The effect of rolling seems to be a breaking up of the large crystals into smaller ones. Jeffries pointed out that "the mechanical working of an aggregate of grains with random orientation gradually changes the orientation of the grain fragments produced by slip toward certain definite positions with reference to the direction of working," i. e., there is a preferred orientation of the grain fragments with respect to the direction of rolling. This preferred orientation increases with successive cold reductions so that a highly worked specimen approaches the condition of a single crystal. In the case of these nickel strips the change in length has been reduced the more the strips have been converted from crystal fragments of random orientation to the state of a single crystal. One might also argue that after the fourth

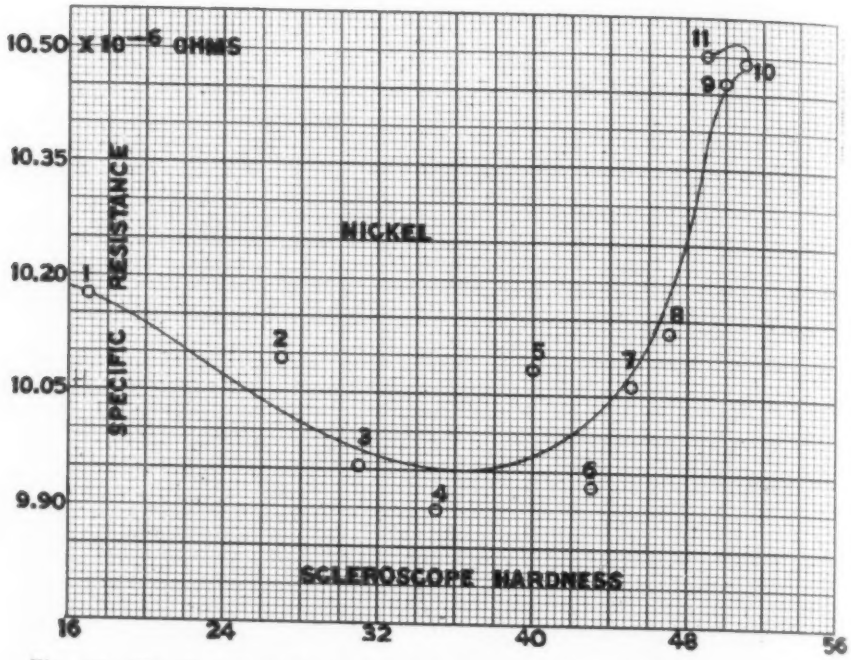


Fig. 11—The Variation of the Specific Resistance in the Eleven Nickel Strips is Compared with the Scleroscope Numbers. This Curve Should be Compared with Fig. 8. Residual Magnetism and Specific Resistance Have Much in Common for Nickel as Others Have Shown to be the Case for Iron.

reduction the alignment of crystals was fairly complete, inasmuch as the change in length remained practically constant for the remaining steps in rolling. Some previous work[5] on silicon steel crystals in the form of strips indicated that the change in length due to a magnetic field was independent of the orientation of the crystal composing the strip. This does not imply a contradiction for even in the case of a single crystal a change in length occurs. The point to be emphasized is that, either by the regular processes such as are used in making single crystals or by rolling, the definite orientation of crystals leads to a closer packing of the crystal fragments which is not favorable to large changes in length. The close packing also favors an increase of hardness. The random orientation of crystals is favorable to large magnetostrictive effects and small hardness numbers.

A close inspection of the photomicrographs indicates that the more the strips are rolled the more compact they become. The dark circular spots seen in 1, Fig. 5, and which are nonmagnetic, grow smaller and smaller with successive rollings. This

[5]S. R. Williams, *Testing*, 1, p. 190, 1924.

seems significant from the standpoint of mechanical hardness and also concerning certain magnetic properties still to be discussed.

To obtain further correlations between hardness and other magnetic phenomena, the following observations were obtained. Hysteresis curves were run for the various rods from which values for hysteresis loss, residual magnetism and coercive force were drawn. Fahy's permeameter was used for this work. Fig 6 shows the half area hysteresis loop for the nickel strips, A_1, and A_{10}, Fig. 7 correlates hardness and coercive force while Fig. 8 shows the relation between hardness and residual magnetism and Fig. 9 demonstrates that for nickel, hardness plays an important rôle in the values of hysteresis loss.[6] Several of these curves indicate as does Fig. 1 that the amount of cold reduction has arrived at a very interesting point when it was reduced 93.3 per cent. It would be of great interest to go still farther in the reduction and see where it leads to in these changes of physical properties.

Barus and Strouhal[7] observed a change in the specific resistance of steel as its hardness was varied. The set of steel rods used in Part 1 was measured in regard to specific resistance. Fig. 10 gives the various specific resistances plotted against hardness and is added here to complete the observations on that set of rods. Rod 6 in Fig. 10 is not included in the curve because it was annealed for two hours and the others were treated for only fifteen minutes and consequently cannot be compared directly.

Fig. 11 is the corresponding curve for the set of eleven nickel strips showing how the specific resistance of these rods vary with the different degrees of hardness. Peirce[8] has shown that the resistivity of hardened cast iron is a measure of its fitness for use in permanent magnets. The similarity of curves in Figs. 8 and 11 indicates that a similar relation holds for nickel as well.

Conclusions

1. The various physical properties of nickel which have been measured in this study are modified by the hardness produced by rolling, similar in many ways, to that produced by heating in the case of steel. It would appear, therefore, that hardness

[6]Ewing and Cowan, *Transactions*, Royal Society, 179, A, p. 332, 1888.

[7]Barus and Strouhal, Wied. Ann., 11, p. 479, 1879.

[8]Peirce, *Proceedings*, American Academy, 46, p. 185, 1910.

produced by these two methods have a great deal in common as viewed from the magnetic viewpoint.

2. Free from extraneous magnetic fields, eleven different specimens of nickel did not show any initial lengthening. The conclusion is that there is also no Villari reversal point for nickel.

3. It is significant that while all the other magnetic phenomena studied in this paper went on changing with varying degrees of cold reduction and hardness, the magnetic change in length did not vary after the fourth reduction. Ultimately all magnetic phenomena must rest on the behavior of the elementary magnet, but thus far one must conclude that the mechanism for change in length must have a factor distinctly different from that which produces the other magnetic phenomena.

DISCUSSION

A. V. DEFOREST: It is very gratifying when other people take an interest in one's hobby, and after playing with magnetics and magnetostriction ideas for a long time without getting very much enthusiasm from anyone, it is pleasant to have somebody show some magnetostrictive effects, as were shown by Professor Williams on the nickel. It is an interesting subject and one which I hope some day will turn out to be of some importance. I think that as far as practical results are concerned, the converse is perhaps of more immediate importance, that is, the use of the magnetic properties as a measure of the mechanical distortion, which is merely turning the thing over. In that case one can look at the question of internal stresses by arguing backward that it must be the stress in the material which has produced the magnetic change, and if you want to prove it, you can easily put the specimen in the testing machine and pull it, applying external stress which will give the same magnetic properties as can frequently be found as a result of internal stress. And if the two check, it seems logical to suppose that there is a connection between them.

The use of magnetic methods for testing hardness is something that I scarcely know what to say about. I do not like the term at all, because there is not any necessary relation. Hardness itself is something we know little about, and magnetism is something we know less about, and to try to correlate the two means to stir up a great many difficulties. The magnetic characteristics of heat treatment and structure and the magnetic characteristics introduced by stress are entirely different. Hardness is produced by both these different methods. The magnetic testing has to be done with a great deal of care, however, or a perfectly hopeless confusion results. And just as almost any property can be used as a measurement of hardness providing all the other conditions remain constant, so magnetic properties can be used in the same way. But if any of the other conditions are upset, that is,

(Continued on Page 1041)

FUNDAMENTAL RESEARCH IN STEEL MANUFACTURE

By Dr. C. H. Herty, Jr.

Abstract

This paper classifies the problems encountered in the making of steel and points out that the field for fundamental research in its manufacture is astounding in its magnitude and intricacies, and that any discussion of the various processes of manufacture and the problems which arise becomes exceedingly involved and voluminous.

The writer has therefore limited his paper to a consideration of the fundamental research which deals primarily with slag-metal reactions giving particular attention to the formation and elimination of nonmetallic inclusions formed from manganese, silicon and aluminum.

He is of the opinion that the problem of solid nonmetallic inclusions in steel is an important one to the manufacturer of this commodity and sets forth the two main lines along which, in his estimation, it is necessary to work to eliminate it.

The author hopes that general cooperation along this line of research will result in a solution of the troublesome question of "solid nonmetallic inclusions in steel."

Classification Of Problems

IN discussing fundamental research in steel-making, it is necessary to divide the entire field into a number of sections. A first classification would be:

1. The blast-furnace process
2. The open-hearth and Bessemer processes
3. Properties of steel during rolling
4. Properties of steel in service
5. New steels or irons.

Each of these may be subdivided into a number of subjects such as:

1. The blast-furnace process:
   (a) Equilibrium between slag and metal

[1]Published with approval of the Director, U. S. Bureau of Mines, and the Metallurgical Advisory Board, Carnegie Institute of Technology.

A paper presented before the winter sectional meeting of the Society, Washington, January 20 and 21, 1927. The author, Dr. C. H. Herty, Jr., is physical chemist, Pittsburgh Experiment Station, U. S. Bureau of mines, Pittsburgh.

(b) Rate of elimination or reduction between slag and metal
(c) Rate of reduction of iron oxides
  (1) Flow of gases in the furnace
  (2) Heat transfer between gases and stock
  (3) Equilibrium between gases and stock
  (4) Mechanism of iron ore reduction.

2. The open-hearth and Bessemer processes:
(a) Equilibrium between gas, slag, and metal
(b) Rate of elimination of metalloids
(c) Slag composition
(d) Slag viscosity
(e) Formation and elimination of nonmetallic inclusions
(f) Solidification of the ingot
(g) Combustion in the open-hearth
  (a) Port design
(h) Heat transfer in the open-hearth
  (a) In the hearth proper
  (b) In the regenerators
(i) Pressure drop through regenerators
(j) Open-hearth refractories

3. Properties of steel during rolling:
(a) Effect of metal composition on rolling properties, (hot and cold rolling)
(b) Effect of rolling on the structure of the metal
(c) Effect of temperature on rolling properties
(d) Heat flow in solid steel.

4. Properties of steel in service:
(a) Effect of composition on serviceability of steel
  (1) Usual chemical analysis
  (2) Nonmetallics, including gases in steel
(b) Uses of new alloys.

5. New steels or irons:
(a) Alloy steels.

Under each of these subdivisions should be placed innumerable other subdivisions until the field for fundamental research is seen to be astounding in its magnitude. Furthermore, each main division is linked into another division by one of the numerous subdivisions.

As it is beyond the scope of this paper to deal with more than the division on the open-hearth process it will be restricted to a discussion of the fundamental research which deals with slag-metal

reactions, with particular reference to the formation and elimination of nonmetallic inclusions, formed from manganese, silicon, and aluminum.

Only two references are taken from the literature, both of which are used to illustrate certain points in the text. It has seemed best in this paper not to refer to the many works which deal with nonmetallics because no data are presented here.

Nonmetallic Content of Steel

Before going into the details of formation and elimination of nonmetallics it must be pointed out that solid nonmetallics, or "sonims," should fall into the same class with phosphorus, sulphur, carbon, manganese, and silicon insofar as specifications for steel are concerned. There are no more grounds for making all steel absolutely "clean" than there are for demanding that all steel should contain under 0.01 per cent sulphur. Furthermore, it is advisable in some types of steel—welding steel for example—to have considerable amounts of nonmetallics, just as it is helpful to have high sulphur for nut and bolt stock and high phosphorus for certain types of sheet.

For every kind of steel it will be necessary to set a specification on nonmetallics and this specification may, in the end, vary with the kind of nonmetallic present. Such a situation holds in the case of sulphur. The specification on sulphur in steel usually varies inversely with the manganese content of the steel, for the reason that the type of sulphide is changed as the manganese content increases. Feild's work on zirconium[2] showed that under certain conditions the sulphur specification for some steels could be raised considerably, provided that a certain amount of zirconium was present in the steel. Here we have the three sulphides, FeS, MnS, and ZrS, showing entirely different effects on the rolling properties of steel.

One of the most important and most fundamental pieces of work is therefore, to determine just how nonmetallics influence the properties of steel with the two factors, amount and type of inclusion, as the major variables. The working out of such specifications would undoubtedly take a long time in view of the many types of inclusions, the many types of steel, and other variables

[2]Feild, A. L., *Transactions*, American Institute of Mining and Metallurgical Engineers, Vol. LXX, 1924, p. 201.

such as segregation, type of service to which the steel is put, etc. That all steel should not necessarily be absolutely clean is one point which must be kept in mind throughout any discussion on nonmetallics. There is, on the other hand, unquestionably an upper limit on solid nonmetallics for various steels which should not be exceeded.

Formation and Elimination of Solid Nonmetallic Inclusions

With regard to the formation and elimination of nonmetallics in open-hearth practice, there are five possible sources thereof, as follows:

1. Nonmetallic matter in or on the scrap charged
2. Nonmetallic matter in the pig iron
3. Nonmetallics formed when the pig iron is introduced into the open-hearth, by the oxidation of the metalloids silicon, manganese, phosphorus, and aluminum, and by the introduction of sulphur from the iron.
4. Formation of nonmetallic matter when the heat is worked with ore or pig iron.
5. Formation of nonmetallics when the final additions are made.

Nonmetallic Matter in or on the Scrap Charged

During the last few years, open-hearth men have emphasized the necessity for using "clean, heavy melting scrap" in order to obtain the best results in making good steel. In the use of such scrap it is probable that the good results obtained are due primarily to the fact that with heavy scrap only a small amount of oxidation occurs during the melting period. For this reason it is possible to calculate the charge so that the heat will melt at the best carbon content, allowing the last 20 to 40 points of carbon to be worked out by the use of suitable additions of ore. On the other hand, with small scrap, it is often true that an excessive formation of iron oxide occurs during melting and the heat melts "soft," thus making it necessary to build the carbon content up by the use of pig iron. It is believed that nonmetallics formed by adding large amounts of pig iron toward the end of the heat, or nonmetallics consisting mainly of suspended iron oxide, impair the quality of the finished steel.

Nonmetallics which exist in the scrap charged are probably

eliminated during the early stages of the heat, and in comparison with other sources they may in all probability be neglected.

Nonmetallic Matter in the Pig Iron

It has often been noticed that a poor quality of steel results from certain types of pig iron. The reason for this is not definitely known, but one possible explanation is that certain solid nonmetallic material is carried into the pig iron in the blast furnace and is of such a character that it is never eliminated in the open-hearth. Pig iron that causes trouble in the open-hearth usually comes from a cold blast furnace, and the silicon in the iron is unusually low. This indicates that unreduced iron oxide or iron silicates may be carried into the pig iron and then into the open-hearth. Just what type of nonmetallic matter is present in this low-temperature iron is, so far as the writer is aware, unknown. However, it is so certain that this type of pig iron will cause trouble in the open-hearth that fundamental research on the effect of low-temperature pig irons on the quality of steel is very important to the open-hearth operator. This involves considerable study on the slag-metal reactions in the blast furnace, particularly with regard to the effect of temperature on these reactions. It also involves a study of open-hearth practice using such pig iron.

Nonmetallics Formed When the Pig Iron is Introduced into the Open-Hearth

When pig iron, particularly hot metal, is introduced into the open-hearth furnace, a very rapid elimination of silicon, manganese, phosphorus, and aluminum takes place. The oxidation of these metalloids forms a large quantity of minute nonmetallic particles, liquid or solid, which must be absorbed by the slag before the heat is tapped. The type of inclusion formed is unquestionably related closely to the analysis of the pig iron and to the oxidation of the molten metal in the furnace at the time of the pig iron addition. For example: high-silicon, low-manganese iron will certainly form a different type of inclusion from a low-silicon, high-manganese iron. As will be brought out later, very definite differences in types of inclusions formed are to be expected from various concentrations of metalloids added to the bath.

The elimination of these nonmetallics primarily depends upon three factors, as follows:

1. The type of inclusion—that is to say, whether the inclusion is liquid or solid and whether the inclusion is a small particle or agglomerated
2. The composition and physical properties of the slag
3. The degree of agitation of the bath.

As a rule, the slags formed during the early period of an open-hearth heat are very fluid, due to their high manganese content and because the lime is somewhat low during this period. The agitation of the bath is brought about by means of the decomposition of the limestone which is charged on the bottom of the furnace.

Fundamental research on this phase of the process divides itself into two distinct problems: (1) research on the type of inclusions formed from various types of pig irons; and (2) research on the viscosities of various types of slags. In both of these problems a very wide range must be covered inasmuch as there is a wide range of pig-iron composition used in the open-hearth, and an even wider range in the composition of slags formed during the melting stage.

Formation of Nonmetallic Matter when the Heat is Worked with Ore or Pig Iron

After the heat is melted, either ore or pig iron must be added, depending on whether the heat melts "high" or "low". In either case, nonmetallic matter is formed, but the type of nonmetallics formed is entirely different. When it is necessary to add ore, the composition of the metal will usually range from 0.08 to 0.50 per cent manganese, from 0.01 to 0.15 per cent phosphorus, and with silicon under 0.02 per cent. The dissolved iron oxide in the bath will be very low under these conditions. Therefore, when iron oxide is introduced into the bath, the inclusions formed will consist mainly of a mixture of MnO, FeO, and ferrous phosphate. The amount of silica formed will be very small because the silicon content of the bath is small. Any gangue in the ore will also be introduced into the bath at this time.

When it is necessary to add pig iron, the composition of the bath will usually be from 0.05 to 0.20 per cent manganese, from 0.01 to 0.03 per cent phosphorus, and only a trace of silicon. The iron oxide dissolved in the bath will be much higher than in the case when ore is added. The nonmetallics formed under this condition will consist mainly of iron and manganese silicates.

formed from the manganese and silicon in the iron, which may have entirely different properties as regards their ease of elimination from the nonmetallics formed when ore is added. It is also possible that Al_2O_3 is formed at this time from aluminum in the iron. Again at this point the important factors in elimination are type of inclusion, slag condition, and agitation of the bath.

Formation of Nonmetallics when the Final Additions are Made

When the heat is ready to be tapped, suitable alloy additions are made either in the furnace or in the ladle, or in both furnace and ladle, and the nonmetallics formed depend upon the oxidation of the bath, which is controlled by the carbon content and the content of iron oxide in the slag, and the kind and amount of additions made. Any nonmetallics formed at this time have much less opportunity to leave the metal than those formed on the addition of pig iron or during the working of the heat. On this account it is probable that these nonmetallics are the most important of any formed, and their elimination will depend more upon their composition and physical characteristics than on any other factor. It is not intended here to minimize the effect of slag viscosity at this point, because this undoubtedly has its effect both on the ability of the slag to absorb the inclusion and on the yield of the element added. Solid nonmetallics formed by additions in the furnace have a much better opportunity to rise into the slag because of the large slag metal area and to the small distance between the slag and the bottom layer of metal. Nonmetallics which are carried into the ladle and to which are added the nonmetallics formed from ladle additions have a much greater height of metal through which they must rise. Furthermore, as the temperature of the steel falls, the increased viscosity hinders the elimination of the solid nonmetallics.

When the heat is teemed, the elimination of nonmetallics is greatly affected by the condition of the steel in the mold—that is, whether the steel is "killed" or effervescent. A very interesting investigation by Dickenson[3] has shown the distribution of solid nonmetallics in certain types of killed steels.

It is unquestionably true, however, that different types of inclusions may show different characteristics from those studied

[3]Dickenson, J. H. S., *Transactions*, British Iron and Steel Institute, May, 1926.

by Dickenson, both as to the amount left in the ingot and as to the size of the inclusion itself.

In effervescing steels, the solid nonmetallics probably segregate just as sulphur does and we should expect to find the surface of a "rimmed" ingot quite free from solid nonmetallics, whereas the center, particularly near the top of the ingot, should show a higher percentage.

Formation and Elimination of Nonmetallic Inclusions

When a deoxidizer is added to a bath of steel, reaction between the deoxidizer and dissolved iron oxide immediately takes place. Two possibilities occur as to the method of formation of the inclusion: Let us take deoxidation with silicon as an example. The first possibility is that the silicon reacts with the iron oxide to give silica by the reaction

$$Si + 2FeO \rightarrow SiO_2 + 2Fe$$

This silica may then react with more dissolved iron oxide to give a ferrous silicate which in turn may simply dissolve iron oxide or silica. The second possibility is that the silicon reacts with iron oxide to form a silicate directly by the reaction

$$Si + 3FeO \rightarrow FeSiO_3 + 2Fe,$$

and this ferrous silicate may dissolve either iron oxide or silica. In either case, the reaction products will depend upon the concentrations of the deoxidizer added and of the dissolved iron oxide.

Figs. 1 and 2 show the inclusions formed by the addition of (1) 15 grams of ferrosilicon to 25 pounds of low-carbon steel and (2) 50 grams of ferrosilicon to another 25-pound lot of the same steel. It is very clearly shown here that two entirely different types of inclusions are formed. The properties of these two inclusions, especially with regard to their agglomerating power, will be the controlling factor in how rapidly the inclusions will be eliminated from the steel. Furthermore, it is entirely possible that these two types of inclusions may act very differently, both in regard to their effect on the rolling of the steel and on the quality of the finished product. Figs. 3, 4, and 5 show inclusions formed by the addition of manganese, silicon, and aluminum to a low-carbon steel, and it is at once evident that the type of inclusion

formed from each of these deoxidizers has a peculiar characteristic all its own. The working out of the mechanism of the formation of each of these inclusions, the physical properties of the in-

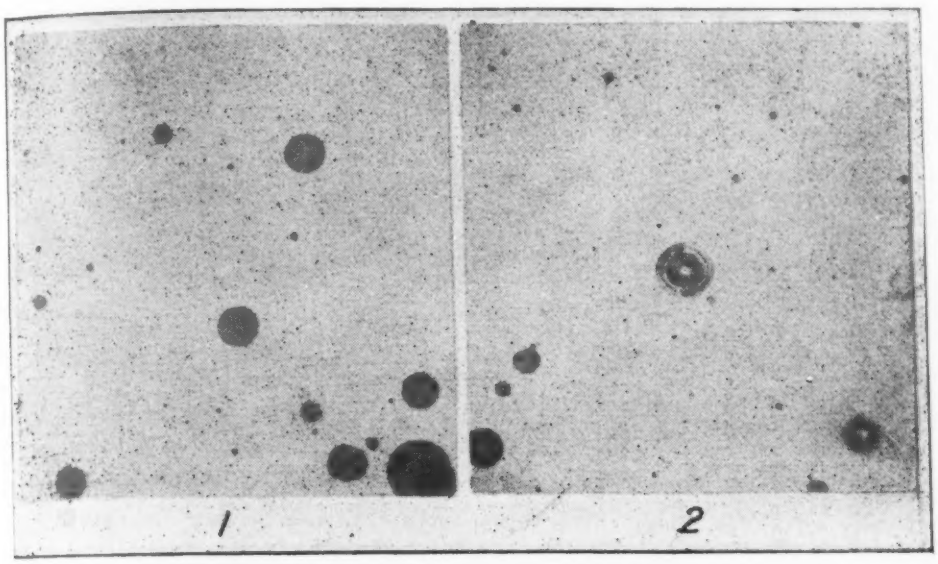


Fig. 1—Photomicrograph of Inclusions Resulting from the Addition of Fifteen Grams of Ferrosilicon to Twenty-five Pounds of Low-carbon Steel. Mag. 200 x. Analysis: Silicon 0.030 per cent, Carbon 0.05 per cent. Fig. 2—Photomicrograph of Inclusions Resulting from the Addition of Fifty Grams of Ferrosilicon to Twenty-five Pounds of the same Steel as in Fig. 1. Mag. 200 x. Analysis: Silicon 0.127 per cent, Carbon 0.05 per cent.

clusions as regards elimination from the steel and the effect of the different types of inclusions on rolling properties and on service conditions of steel, constitute the work of the Metallurgical Section of the Pittsburgh Experiment Station of the U. S. Bureau of Mines.

Rate of Elimination of Inclusions

In determining the rate of elimination of inclusions the three most important factors are:

1. The nature of the inclusion
2. The viscosity of the slag and metal
3. The temperature.

1. *Nature of the Inclusion*

The nature of the inclusion is determined by:

(a) The concentration of dissolved iron oxide in the metal at the time the deoxidizer is added

(b) The concentration of the deoxidizer, or deoxidizers, in the steel

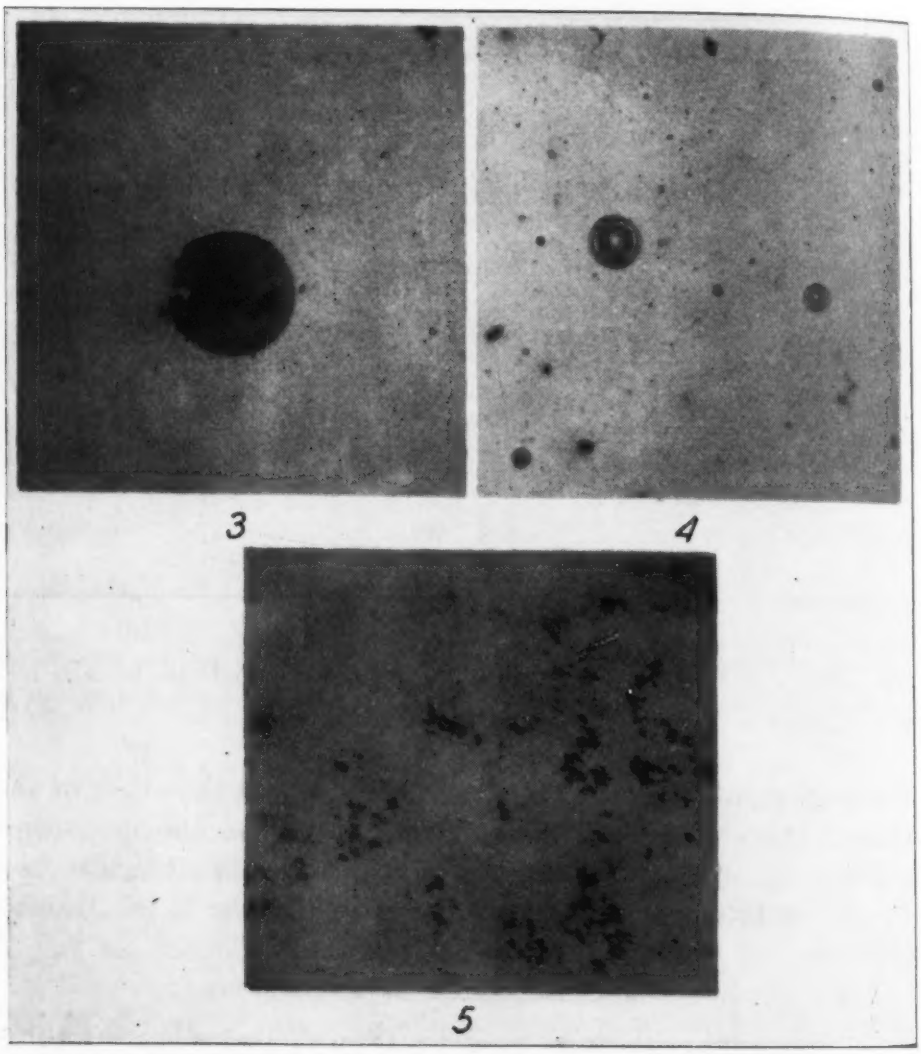


Fig. 3—Photomicrograph of Inclusions Resulting from the Addition of Ferromanganese to a Low-carbon Steel. Mag. 200 x. Fig. 4—Photomicrograph of Inclusions Resulting from the Addition of Ferrosilicon to same Low-carbon Steel as of Fig. 3. Mag. 200 x. Fig. 5—Photomicrograph of Inclusions Resulting from the Addition of Aluminum to same Low-carbon Steel as of Fig. 3. Mag. 200 x.

(c) The relative rates of deoxidation, if two or more deoxidizers are present

(d) Equilibrium conditions in the system FeO, MnO, SiO_2 and Al_2O_3

(e) The temperature

(f) Solution of FeO into the steel from the slag after the

deoxidizers are added, which continually changes the concentration of FeO in the steel.

The two most important properties which inclusions should have are: (1) the property of agglomeration, the larger the particle the more rapid is the upward settling through the steel; (2) the power to combine with or be dissolved into, the slag, once it is brought to the slag-metal surface. Both of these properties are closely related to the state of the inclusion—that is, liquid or solid, and to the surface tension of the inclusion.

2. *Viscosity of Slag and Metal*

Every open-hearth operator is familiar with the statement that "to make good steel you must make good slag." Unfortunately, no one seems to know why a certain type of slag, usually spoken of as "creamy," gives the best results in regard to the quality of the steel produced. The viscosity of the slag is certainly the controlling factor in the manner in which a slag "works" in the furnace, and it is probable that a definite relation exists between viscocity and surface tension, and this property is undoubtedly a controlling factor in the ability of a slag to absorb inclusions which are brought up through the metal to the slag-metal surface. The viscosity of the slag is controlled by its composition and temperature.

The viscosity of the steel is important in that it is the controlling factor which governs the rate of upward settling of a given inclusion. The viscosity of the steel will vary with temperature and composition. No data have been reported on this subject.

3. *The Temperature*

The temperature of the bath affects almost every factor which has been outlined. Equilibrium conditions between slag and metal, equilibrium in the metal phase, the physical properties of the various inclusions, relative rates of reaction, diffusion of iron oxide from slag to metal, and viscosity and surface tension of slag, metal, and inclusion are all affected by temperature. Very little is known of the quantitative effect of temperature on any one of these factors.

The following fundamental studies must be carried out before the formation and elimination of inclusions may be thoroughly understood:

1. Equilibrium between slag and metal:

(a) Effect of temperature and slag composition on the solubility of FeO in iron

(b) Effect of temperature and slag composition on the solubility of MnO, and other nonmetallic substances

2. Equilibrium in the metal phase:

(a) Equilibrium between FeO, the various deoxidizers used, and the deoxidation products

(b) Equilibrium between carbon and dissolved iron oxide

(c) Effect of temperature on these equilibria

3. Relative rates or deoxidation of manganese, silicon and aluminum:

(a) Effect of temperature and concentration in the metal

4. Equilibrium conditions in the four-component system FeO, MnO, SiO_2, and Al_2O_3:

(a) Binary, ternary and quaternary diagrams.

5. Rate of diffusion of FeO from slag to metal:

(a) Effect of concentration of FeO

(b) Equilibrium between Fe, FeO, and Fe_2O_3

(c) Effect of slag composition

(d) Effect of slag viscosity and surface tension

6. Surface tension and viscosity relations in the system FeO, MnO, SiO_2, and Al_2O_3:

(a) Effect of temperature

(b) Effect of composition

7. Agglomeration of inclusions:

(a) Concentration

(b) Surface tension

(1) Composition

(2) Temperature

8. Surface tension and viscosity reactions in slags:

(a) Effect of composition

(b) Temperature

9. Viscosity of steel:

(a) Effect of temperature

(b) Effect of composition

10. Rate of upward settling of inclusions:

(a) Density of inclusion
(b) Size of inclusions
(c) Condition and shape of inclusions (liquid or solid)
(d) Effect of viscosity of steel

11. Rate of absorption of inclusions by slag:
(a) Effect of surface tension and viscosity of slag
(b) Effect of surface tension and viscosity of inclusion.

Each of these is a fundamental study which covers a very large field inasmuch as there is a tremendous range in composition of open-hearth slags, a very large range in viscosity of open-hearth slags, an almost unlimited range in composition of inclusions, and a considerable range in temperature over which the reactions may take place.

Conclusion

In order to attack the problem of solid nonmetallic inclusions in steel, it is necessary to work along two lines—namely,

1. The effect of inclusions on the rolling and service quality of steels, with particular regard to the amount and type of the inclusion present.

2. The formation and elimination of inclusions.

This, of course, is a tremendous field for research and it is not to be expected that the whole answer to solid nonmetallic inclusions may be obtained by any one laboratory. The U. S. Bureau of Mines, in conjunction with the Carnegie Institute of Technology and their Metallurgical Advisory Board, is carrying out certain phases of this general problem. The results will be published from time to time and it is hoped that this work may be correlated with other fundamental work to settle as definitely as possible the question of solid nonmetallic inclusions in steel.

DISCUSSION

Written Discussion: By T. D. Lynch, Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa. Dr. Herty's paper gives us a glimpse of the great problem of "Physical Chemistry of Steel Making" and points out the significance of its careful and scientific study.

A successful solution of the various phases suggested, together with its commercial use, can but result in cleaner and more dependable steel such as will respond definitely to the heat treating processes of our recommended practice committee and enable our designing engineer to use them safely with a much lower factor of safety. More definiteness, more safety, more economy.

This is an era of economical production and any index that points toward greater uniformity of steel points the way to greater safety and with it greater ultimate economy.

Oral Discussion

DR. H. W. GILLETT: It seems to me that if I were purchasing steel for purposes for which quality was desired, a good method of gaging the real desire of the firm to supply steel of high quality would be to find out how much interest that firm was taking in this work of Dr. Herty's. I believe that this question is at the very foundation of more difficulties, more abstruse and mysterious difficulties than we realize at the present time.

LEON CAMMEN: I believe that this is one of the most important papers that I have seen in a long time.

In this paper, in work along those lines which Dr. Herty described, we are gradually getting an understanding—this is the first clear glimpse into it—of what molten steel really is. We have been talking about what forms the constituents, but just what is molten steel? We know that we have iron, carbide of iron, and various so-called impurities, such as sulphides, silicates, silicides and so on, but in what form do they occur?

The question may be formulated even more precisely: Is steel a crystalline solution or is it a colloidal solution? Some 15 years ago nobody doubted but what it was a crystalline solution. Since then more and more information has been accumulating to show that it may or may not be so.

We know for example the profound changes which vanadium, and to a smaller extent, molybdenum, creates in steel. The action of vanadium is, obviously, not a purely chemical one. It is now claimed that it acts as a catalyzer; or more likely as a protective medium to prevent gelatinization of certain constituents of steel. Now Dr. Herty indicates that certain constituents begin to grow and then stop growing. If steel were a purely crystalline solution, such a phenomenon would be extremely difficult to explain. If it is a colloidal solution, then we have simply the interruption of the condensation phase at a certain point, which is a phenomenon quite familiar to all those who work with colloidal solutions.

The fact that a given form of this constituent first disappears and then appears again would also indicate that we are dealing with colloidal phenomena. We have first the gelatinization phase, then we have peptization and there is already reason to believe that such a peptization process starts with a highly dispersed state followed by condensation.

Sometime ago Dr. Gillett published an article, I believe in the Forging, Stamping and Heat Treating, in which he discusses what happens in a ladle of steel when filled and set aside for 20 minutes or so, and showed that this period of restitution produces a certain elimination of so-called impurities. Lately in Germany they have been trying to eliminate some of the sulphur compounds by violently shaking molten pig iron before using it. Here again if steel were a crystalline solution no amount of shaking or no amount of resting of the metal would affect the contents of the solution short of an accompanying change of temperature. If it is a colloidal solution, however, we can

easily see how violent agitation on one hand or rest on the other hand would affect the condensation phase of the material and by gelatinization force its elimination. There is a question that arises in my mind here, and that is,—do we not often call our best friends by bad names? We are inclined to consider phosphorus and sulphur as impurities. But if molten steel is a colloidal solution, sulphur and phosphorus within reason and in certain forms may act as a protective medium, and therefore be absolutely indispensable to the making of good steel, so that if we succeeded in eliminating phosphorus and sulphur completely we might get worse steel than we are now getting. Electric sheet, sheet made of low carbon steel, and without any phosphorus, is much poorer in its electrical qualities than sheet made with phosphorus. Therefore, I welcome very much Dr. Herty's investigation as probably the first indication that the time has come and that we are far enough advanced to make it possible to investigate just what kind of a solution steel is and what really is going on in it.

G. A. DORNIN: All I can say in discussion of this paper is that no one welcomes it more than I do. I agree with Dr. Herty in everything he says, and I think our knowledge as far as the use of this knowledge in steel making may go today is a crude piece of guesswork. I think we hardly know what we are doing. Our best guess in making forging steel or clean steel is that we have to form, when we deoxidize, some fusible combination of the three oxides that Dr. Herty speaks of, manganese oxide, silica and alumina. Beyond that we have not much knowledge but we need a lot of it.

DR. H. W. GILLETT: One of the great difficulties in this field is that it obviously divides itself into two main phases, one is an old line chemical problem as to the control of what is available to form non-metallics, the second is a colloidal chemistry problem. In the second we strive to eliminate the non-metallics from a colloidal suspension, but we lack a sufficient foundation in colloidal chemistry to apply that science to the situation with which we are working here. The colloid chemist ordinarily deals with things that he can handle at room temperatures in the laboratory, for example aqueous solutions, from which he develops a few apparently fundamental laws. The extrapolation from such experiments, for example, a soap water emulsion with a little clay in it, a typical system the student of colloid chemistry might use to study fundamental principles, to the conditions in molten steeli is a long jump up the extrapolation curve, with few points between. So that it seems to me that a campaign of education is necessary; that the steel maker and the steel user must obtain those people who at the present time have the most vision of colloid chemistry—those who have a basis on which to work—to get them interested in this field, even though it may be difficult for them to work in it. If they could, in a university laboratory with 15 cents worth of apparatus drawn from the storeroom, handle these problems, we would know a whole lot more about it. That we do not already know more is because of the innate difficulty of getting into the inside of steel at the temperatures in question and getting any of the ordinary means of identification of what is going on to apply. In this work we need the combination of the metallurgist, the ordinary old line chemist, the physical chemist and the colloid chemist. Fortunately those

qualities are well combined in Dr. Herty, but he needs a great deal of aid, and I think that this Society can do a great deal in bringing the problem to the attention of people with whom we come in contact, who are interested in the field of physical and colloid chemistry, to get them to see whether those laws and conclusions which they deduce on the basis of an entirely different set of conditions can be extended to the conditions with which we have to deal in the system at hand. If we can do that, that will give us more aid along the side lines and will help Dr. Herty to carry the ball over to a touchdown.

F. R. PALMER: From everything that has been written and said so far, a person might easily be excused (if he does not know much about the subject) for thinking that all steel is full of slag and that the steel maker is at his wits end to know how to get rid of it, and I just want to read into the minutes the fact that that is not true. No steel is absolutely free from non-metallic impurities. These are particles so small that they must be seen under a high-powered microscope in all steel, but the silicates, slags and oxides which are the principal subject of our discussion, are not necessarily present in all steel. Many users in the automobile plants, in the airplane industry and in the pneumatic tool business have specifications written, in which there must be no slag in the steel, and steel is being made to those specifications.

I think it is well to read into our minutes, for the benefit of some who might misunderstand, that the steel maker is not absolutely helpless in the face of these things, and while we still have much to learn, and many of the things that we know by rule of thumb we cannot explain scientifically. Nevertheless slag is not an absolutely necessary evil in steel, and it can be gotten rid of. It can be reduced to a point where the hot acid etch cannot find it, and those of you who have used the hot acid etch know that it is a very searching test. It is not uncommon, in order to meet certain very rigid specifications, to make steel which can meet the hot acid etch test. As many as one hundred discs have been taken out of one heat of steel and not a particle of slag was found in any disc.

DR. HERTY: I wish that we could get a really good colloidal physical chemist to thinking about some of these things. I do not know a thing about colloidal chemistry except from what I have learned in general. I know the general principles of colloid chemistry, of course, but I do think that the colloidal chemistry study of steel is going to be the most important of all.

Now, there are certain things in the relations between the slag and metal that can be explained nicely by the straight laws of physical chemistry. There is no question about that. But, on the other hand, those are the things which are somewhat apart from the formation of non-metallics. That is a little different proposition. We can control phosphorus, sulphur, manganese and so forth. We know how to get at the relations between the slag and the metal. But, as Mr. Cammen said, we must do a great deal of colloidal chemistry work in order to obtain data on these other relations. And I believe that, as Dr. Gillett says, the best way to obtain this goal is through educational propaganda in those universities where they have good colloidal chemists. The only reason they have not thought about the colloidal aspects of molten steel is because few

(Continued on Page 1015)

CENTRIFUGAL CASTING OF STEEL

By Leon Cammen

Abstract

The first part of the paper deals with the more familiar subject of centrifugal tube casting, which is a comparatively old art, and shows its present and prospective field of application and limitations, particularly where centrifugal tube casting comes into competition with the piercing process.

The second part of the paper is devoted to the new art of centrifugal bar casting, affecting the entire steel industry. Its importance lies in its ability to produce metal of better quality at a cost estimated to be from $3.50 to $8.50 per ton lower than present methods. The mechanical and metallurgical features of the process are explained, and the machinery employed is described and illustrated in some detail.

WHILE centrifugal casting of steel is barely out of its swaddling clothes, the art of centrifugal casting as a whole, particularly of hollow objects, is quite old and has been practiced on a commercial scale since the beginning of the last century. The earliest English patent (Eckert) dates back as far as 1809 and the earliest American patent to Lovegrove was issued in 1848. At about the same time Andrew Shanks, in London, England, began to make cast iron pipe by pouring molten metal into a spinning wrought iron mold. His process was described in America in the *Scientific American* of December 1, 1849, and it is of interest to note that in the basic features of design, the Shanks machine does not differ much from the majority of machines making tubes in a cold mold at the present day.

A survey of the literature and of the numerous patents issued on centrifugal casting in this country and in Europe would indicate that as far as tube casting is concerned practically all the essential features were covered by patents issued prior to the beginning of the 20th century, with the exception, however, of those dealing with the temperature control of the metal which is a new feature. It would appear that as far as patents are concerned there is no reason why any good engineer could not design

A paper presented before the winter sectional meeting of the Society, Washington, January 19, 20, 1927. The author, Leon Cammen, is associate editor of *Mechanical Engineering* and a consulting engineer, New York.

today a machine for casting pipe without infringing on any of the basic patents. It is, however, necessary to remember that this applies only to the patent situation and that a thorough knowledge of the technical features involved is absolutely necessary in order to design an efficient machine. It might also be well to remember that while the basic features of the general process of tube casting are common property, those who have developed minor features and covered them by patents may be quite anxious to protect their rights. Because of this a thorough familiarity with the patent situation is desirable to avoid involuntary infringement by using some such minor detail as a particular type of pouring spout that has been covered by a patent. It is to assist in this that Appendix II has been prepared, giving, as far as the author is aware, a complete list of all patents on centrifugal casting issued since 1848 up to the end of November 1926 by the United States Patent Office.

When it comes to bar casting, the matter of patents becomes rather simple in a way, there being only a few of them. As nearly all of them have been taken out in the writer's name, he prefers not to express here any opinion as to their scope.

In speaking of centrifugal casting of steel a clear distinction must be made between the more or less well-known art of centrifugal casting of pipes or tubes and the new art of centrifugal casting of bars. The purpose of the former is plain. The casting of bars is for the purpose of rolling them into such products as sheet bars, plate bars, wire rod, rails, structural material, plate and the like. This is a comparatively new departure and more will be said about it later.

While centrifugal casting is done to a small extent on a vertical and inclined axis, the usual way is by introducing molten metal into a mold spinning on a horizontal axis. This is comparatively simple when dealing with such a metal as cast iron, because temperature conditions there are suitable and the metal can be superheated if necessary. With steel, whether plain carbon or alloy, several complicating factors have to be taken into consideration. For many reasons it is not desirable to cast superheated steel, and in fact, the best castings are obtained from comparatively cold metal. This, combined with the rapidity with which steel chills, makes its delivery through long spouts impos-

sible except where very large amounts of metal are involved. It becomes, therefore, necessary to use a comparatively short spout and this, with cold molds, limits the length of the mold, and hence the casting. Longer castings can be obtained by using a hot mold, at the expense, however, of additional trouble and cost of heating and handling the mold.

There is another feature, applying particularly to steel and special ferrous alloys of low carbon content, which also contributes to the necessity for using a very hot mold in centrifugal tube casting (in this connection attention must be called to the fact that the present part of the paper deals exclusively with *tube* casting, as conditions are entirely different in the newly developed art of centrifugal *bar* casting). Assume that we are casting a steel tube, to be used as a hollow blank for a seamless tube mill, 8 feet long, 10 inches outside diameter and 7.5 inches inside diameter. The weight of metal in such a tube is so large that, with a spout extending into the mold for a distance of, say, 4 feet, there is no trouble to deliver metal in such a manner that a tube of uniform thickness from end to end will be formed even when the temperature of the mold is only 350 degrees Fahr. This does not mean, however, that the tube will be good. As the first metal is delivered against the fairly cold wall of the mold, it forms a thin tubular shell which immediately contracts on cooling, with the result that the cast tube lies loosely in the mold. This condition is aggravated still more by the fact that the mold, heated by the contact with the very hot metal, expands. The result of the combination of these two conditions is that the cast tube, while subject to centrifugal stresses in the process of its formation, receives no support from the mold. The centrifugal stresses in this case are fairly large, 75 to 100 pounds per pound of metal cast, while the mechanical strength of the shell of a centrifugally cast tube, with molten metal all the time coming on top of it, is naturally low, and cracking of the cast tube results.

The above explains why tubes cast in cold molds as a rule crack longitudinally and not circumferentially. The centrifugal stresses in a tube in the process of being cast are essentially the same as those produced by water pressure in a cylinder, and it is common knowledge that this is why cylindrical boilers are usually single-riveted in the circumferential seams and double or triple riveted in the longitudinal seams.

This cracking does not occur as frequently in casting in a highly heated mold, first because the casting does not contract away from the mold until after the spinning has ceased, and second, because the mold itself is so hot that contact with the cast tube does not produce expansion to any material extent.

Commercial Possibilities of Centrifugal Tube Casting

From a commercial point of view a distinction should be made between centrifugal tube casting in metals which can be pierced and in metals which cannot. Where the metal cannot be pierced, as is, for example, the case with certain chromium and manganese alloy steels, centrifugal casting appears to be one of the few possible solutions of the problem, very likely the best, and there the question is not so much making the casting at a cost, as producing a hollow billet at all. It is believed that under these conditions centrifugal casting has a bright and promising future. Short or heavy wall tubes can be made in what may be referred to as cold molds and tubes of very considerable lengths in molds heated to the proper temperature. More about this question of temperature will be said later.

Where the metal can be pierced, the commercial value of centrifugal tube casting becomes less certain. Only one tube at a time can be cast in a centrifugal casting machine which means that for each tube there is a considerable amount of handling. Judging from the practice in centrifugal casting of cast iron pipe, most of the operations are manually controlled. Centrifugal casting of cast iron pipe competes with hand-molding, a labor-devouring process, and yet it is quite doubtful whether centrifugal casting costs less than hand-molded pipe. That it costs less to make steel tubing say up to 6 inches by piercing than by casting, is fairly certain. It is only in larger sizes that centrifugal casting begins to loom as a competitor of pierced billets. It is however too early to say today which will ultimately prevail, as our experience with piercing large billets on a commercial scale is only a few months old while centrifugal casting of steel on a large scale is non-existent. Because of this where the billet piercing can be done reliably and comparatively cheaply, the prospect of competition on the part of centrifugal casting of tubes as a starting material for seamless tube manufacture is still uncertain. Emphasis should be made, howewer, on the reliability of the pierc-

ing process. Several companies under pressure of the demand for oil-country goods jumped into big seamless tube manufacture. Speaking colloquially, they all claim that the "water is fine." Within a year or so we shall probably know exactly what it costs to pierce a 12-inch billet, and then we may find that with all its disadvantages casting the hollow billet centrifugally, particularly in a hot mold, may prove to be a good deal cheaper than handling it in the mammoth piercing mills of today.

Centrifugal tube casting finds, however, even in plain carbon steel, a field of application of its own where it does not come into competition with the piercing process. This applies, for example, to the casting of very heavy wall tubes. Lately, the Watertown Arsenal developed a method for the manufacture of small guns, where the start is made with a centrifugally cast hollow billet, which is then machined and submitted to the reinforcing process developed at the Arsenal by Dr. F. C. Langenberg.

Another application of centrifugal casting which bears material promise is under development now and deals with the casting of tubes of very large diameter, 60 inches and over, to be used for the production of high pressure steam boilers (say 900 pounds per square inch pressure and up).

The Art of Centrifugal Tube Casting

Centrifugal tube casting involves certain mechanical and metallurgical problems. We shall start with the latter. Earnest attention is called to the fact that metallurgically centrifugal tube casting is entirely different from centrifugal bar casting. The general belief that in centrifugal casting all impurities will be thrown out of the metal and delivered to the inside face of the casting in a manner somewhat similar to what occurs in milk separators, is based on an incomplete understanding of facts. This will happen where the impurity is a big lump of clay, say, ¼ inch in diameter, and up, but not where we deal with comparatively fine sonims. The viscosity of the metal is so great and the time during which the metal remains liquid and is subject to the action of centrifugal force is so short, that as a rule the finer impurities will be found in that part of the pipe to which they were delivered by the flow of metal.

On the other hand, segregation is materially absent in properly cast tubes which is due to the same causes which prevent

the travel of impurities to the inner face, namely, the lack of time for the transfer of sonims and sulphur, phosphorus, silicon, manganese, and carbon compounds, from one part of the cast tube to another. It is, therefore, as important in centrifugal casting to use clean steel, as it is in ordinary casting.

From a mechanical point of view a distinction must be made between casting in a cold mold (which means a mold heated to about 300 to 400 degrees Fahr.) and casting in a hot mold (of the order of 1000 to, say, 1600 degrees Fahr.). In any event the machine must be substantially built with large factors of safety, set on an extremely solid foundation (the author in his work always uses under the machine a monolithic concrete pad not less than 6 feet thick) and well balanced. The matter of support of molds in tube machines is a comparatively simple problem. In the case of cold molds, it is sufficient to have the mold, which may be made of steel or cast iron, enclosed in a heavy steel tube and provided with thin (say, ½-inch) ribs bearing against the outside tube. Where a hot mold is used, the mold should be made only of materials that do not rapidly deteriorate under the action of heat and that do not lose their hardness at the temperature at which the mold is employed. Among such materials may be mentioned, for example, the so-called Becket metal, which is an iron alloy containing from 18 to 22 per cent of chromium. The utmost attention should be paid to have the mold thoroughly supported in its entire length over at least one-third and preferably one-half of its outer surface. The writer did this by the use of sliding gibs explained in detail in his paper (Centrifugal Casting) presented before The American Society of Mechanical Engineers, vol. 44, 1922, pp. 267-268. A modified design of a later date is shown in Fig. 1. In this design only one of the supporting elements has forward motion, while the others are stationary.

Hot Molds

Hot molds used in centrifugal tube casting have to be protected from the solvent action of molten steel. This may be done in several ways. Where an extremely low carbon steel is used, a layer of oxide on the internal surface of the mold will be satisfactory. It should not be used, however, where the carbon content exceeds say 0.10 per cent, as there the oxide on the surface

of the mold is reduced by the carbon in the steel; gas is formed and as it has no other way to get out except through the metal, blowholes result. These blowholes, by the way, have a peculiar shape, somewhat like pears, with the thin end towards the mold.

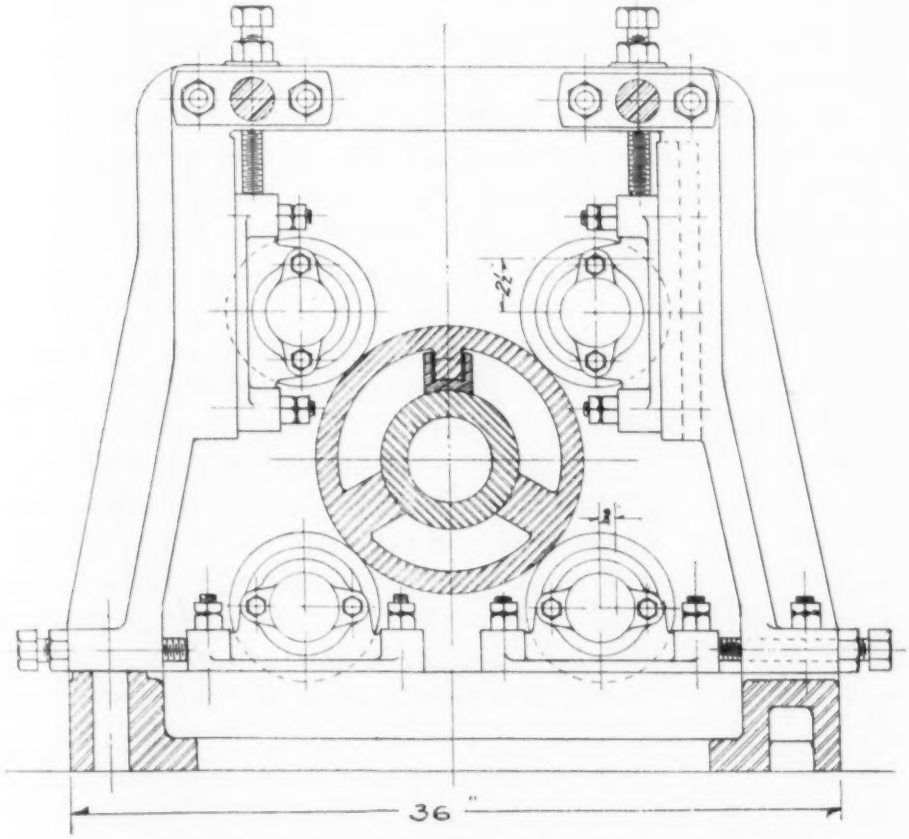


Fig. 1—Machine for Casting Centrifugally Steel Tubes in a Hot Mold.

The writer has tried several combinations including clay, kaolin, etc., but ultimately came to the conclusion that the best material is castor oil, alone or with enough lampblack to bring it to a molasses-like condition. This should, of course, be applied before the mold is heated. In this connection might be mentioned a curious thing about castor oil which the writer had occasion to note in casting duralumin tubes some years ago. The molds were heated to about 1200 degrees Fahr. after having a coating of castor oil applied to them. When the cast tubes were withdrawn, they had an outside surface as smooth as glass, and *were actually wet with oil.*

There is no general formula for determining the temperature of molds in centrifugal casting. It depends on the freezing characteristics of the metal cast, thickness of wall of the cast tube, length of casting, and several other features. As a general rule, it may be stated, that it is advisable to teem the metal as cold as possible, even when this implies heating the mold to an especially high temperature. When the metal to be cast is "superheated", an enormous quantity of heat is released at the time of freezing of the metal, and there is serious danger of the mold burning out. We had several instances of this in casting stellite which melts at a temperature much lower than steel, but is cast in a superheated condition. In casting monel metal, however, melting some 400 degrees Fahr. higher, we never had a case of a mold burning through.

The mold in centrifugal casting has to be heated to some extent in any event to prevent the presence of moisture on the mold wall. If such moisture is present, it forms, upon contact with molten steel, high pressure steam which expands explosively and in doing so and trying to make for itself a path of escape, forms blowholes on the outer surface of the cast tube. It is advisable, therefore, to have the mold heated to at least 300 degrees Fahr.

As regards the speed at which the machine should be run, the writer has no definite information on the casting of tubes of small diameter (7 inches O. D. and under) and substantial thickness (2 inches and up). For the casting of tubes, however, which are either of small diameter and also small thickness, or larger diameter and practically any thickness, the formula

$$\frac{1750}{\sqrt{r}}$$

(where r is the radius of the casting in inches) may be employed. Where the thickness of the tube is material, the inside radius should be used for purposes of calculation. Once the necessary speed has been determined, it is important to see that it is actually produced during the only time when it really counts, and that is, during teeming. As the metal comes in from the spout, it has to be brought up to full speed in a rather short time, an operation which consumes a large amount of power. With a motor which will easily carry to full speed an empty machine, there may be an appreciable slowing down when the metal begins to

come in, and as a result there will not be enough centrifugal force and the casting will be poor (this affects especially the inner surface).

Structure and Segregation

The matter of structure and segregation in centrifugal tube casting of steel is generally misunderstood. As a matter of fact, there is no such thing as specific structure of centrifugally cast steel, and the same applies to segregation. Both of these depend entirely and nearly exclusively on the rate of freezing of the metal. Gun tubes are now cast centrifugally in the form of a cylinder, 15 feet long, say 10 inches diameter, and 5 inches wall. As the tubes are very thick, and the mold in which they are cast is provided with a heavy refractory lining, the rate of freezing is so slow that it takes something like 1½ hours for the metal to solidify completely. The structure of the metal is essentially the same as that produced in a stationary mold under the same conditions, namely, a clear dendritic, with the addition that the carbon content is distributed by the centrifugal action substantially the same as would be cream in a poorly working separator. It so happens that in this particular case such a distribution of the carbon is desirable, while the dendrites can be eliminated more or less by proper annealing. At the same time it may be noted that the same distribution of carbon may be secured with rapid cooling by the method used by J. C. Davis in making the Davis wheel, viz., supplying a regulated stream of high carbon metal to the low carbon metal cast in the mold.

Where the freezing of the metal is rapid, a fine grain free from dendrites is obtained (cp. Fig. 5, a ball race chromium steel, 1.10 per cent carbon, annealed but not worked), while segregation and irregular distribution of carbon are reduced to a minimum.

The selection and use of the spout may have a good deal to do with the success of centrifugal tube casting. The spout should always be so used as to discharge the steel sidewise and not endwise, preferably so that the rotation of the tube should carry the metal under the spout, and it is well, especially in casting large tubes, to experiment a little with the location of the spout, and after the best location has been found, see to it that it is used. It is well to place the spout as near the wall of the mold as the thickness of the casting will permit. Where the spout is clay-lined, it should be carefully inspected before and after each cast-

ing, to make certain that no bits of clay have become loose, and a spout should never be patched up between two castings, as the action of the hot metal is apt to loosen the patch or cause further cracking around it due to the expansion of steam in the patch. Only high grade refractories should be used in the patch, and it should be properly dried before being used. The utmost care should be taken to have the spout well supported: the writer knows of a case where this was not done, and the resulting mess was anything but pretty. The hotter the spout, the better it is, and where casting is done on a regular schedule, it is a good plan not to let the spout cool off much between casts.

Centrifugal Bar Casting

This is to all practical purposes a new art. While several attempts have been made to cast bars, gears etc., in the past, none of these led to satisfactory results and practically all such attempts were usually abandoned after a few trials and without comprehension of the reasons which made the attempt abortive.

Referring to Fig. 2 and considering only the barrel part of the mold A, one will see what amounts to a mold for casting tubular shapes. It differs from such a mold, however, because of the presence of partition lugs B. Assume now that we employ this mold in the same manner as we would employ a mold for making tubular castings, as has been actually done by a number of would-be inventors of centrifugal bar casting. Offhand one would suppose that the problem is very simple. Centrifugal force throws the metal to the wall and if the metal be delivered to such mold as shown here it ought to be thrown to the bottom of the cavities between the partition lugs and form little ingots therein. It actually does it in as far as the forming of the ingots is concerned. The only trouble is that the metal thus formed is absolutely worthless. A clear understanding of the reasons for this failure will give an inkling as to the metallurgical mechanism of centrifugal bar casting.

The mold shown in Fig. 2 is spinning on a horizontal axis. The partition lugs may be anywhere from 5 to 15 inches long, the inside diameter of the mold from 50 to 100 inches and the speed of the order of 6000 feet per minute on the inner surface. When molten metal is coming down from the spout into a mold of this size and running at such a speed, it is apt to be hit by

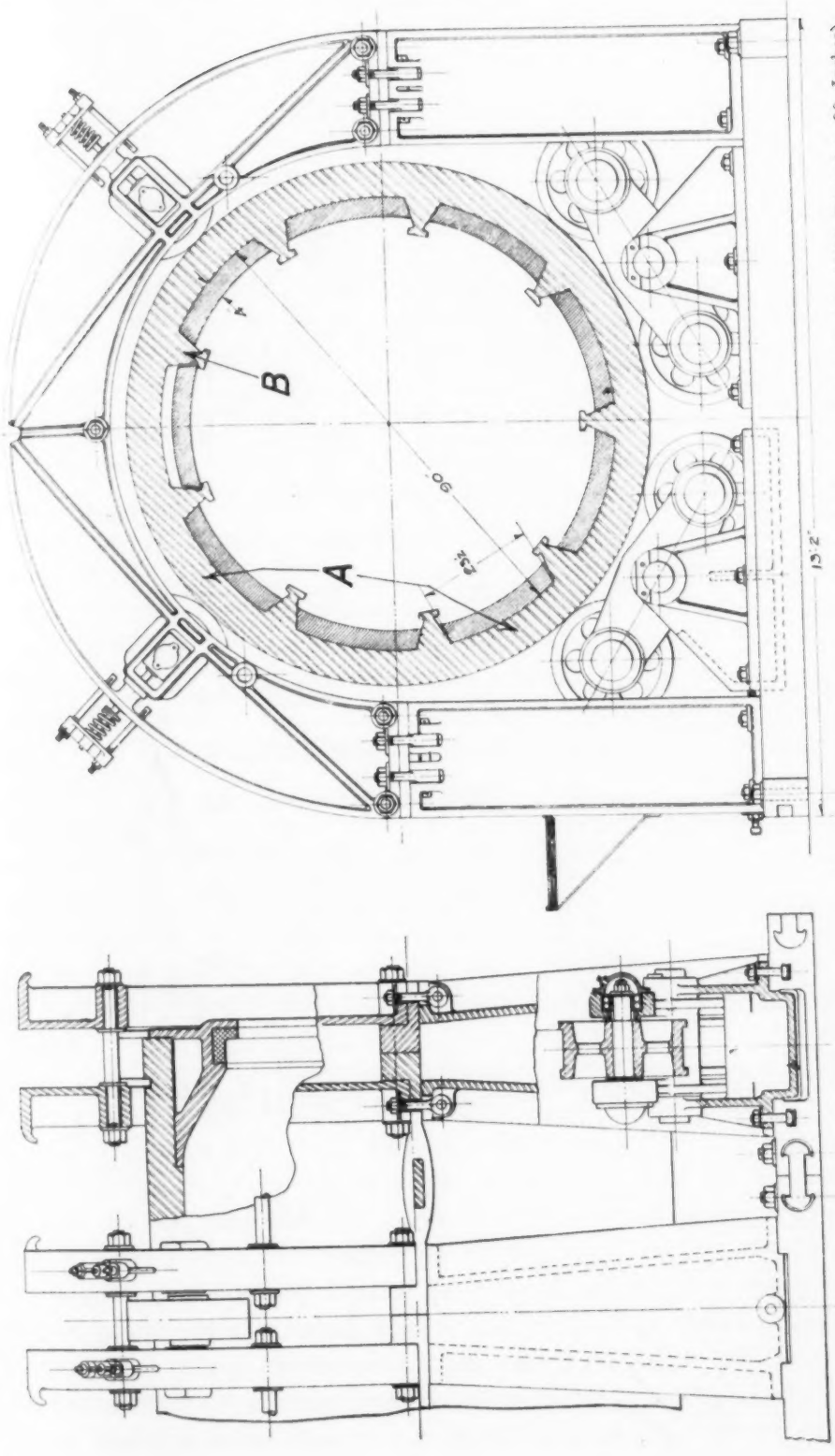


Fig. 2—Centrifugal Bar Casting Machine, Section Through Vertical Plane at Right Angle to Axis of Rotation (Inside Mold Diameter 90 Inches).

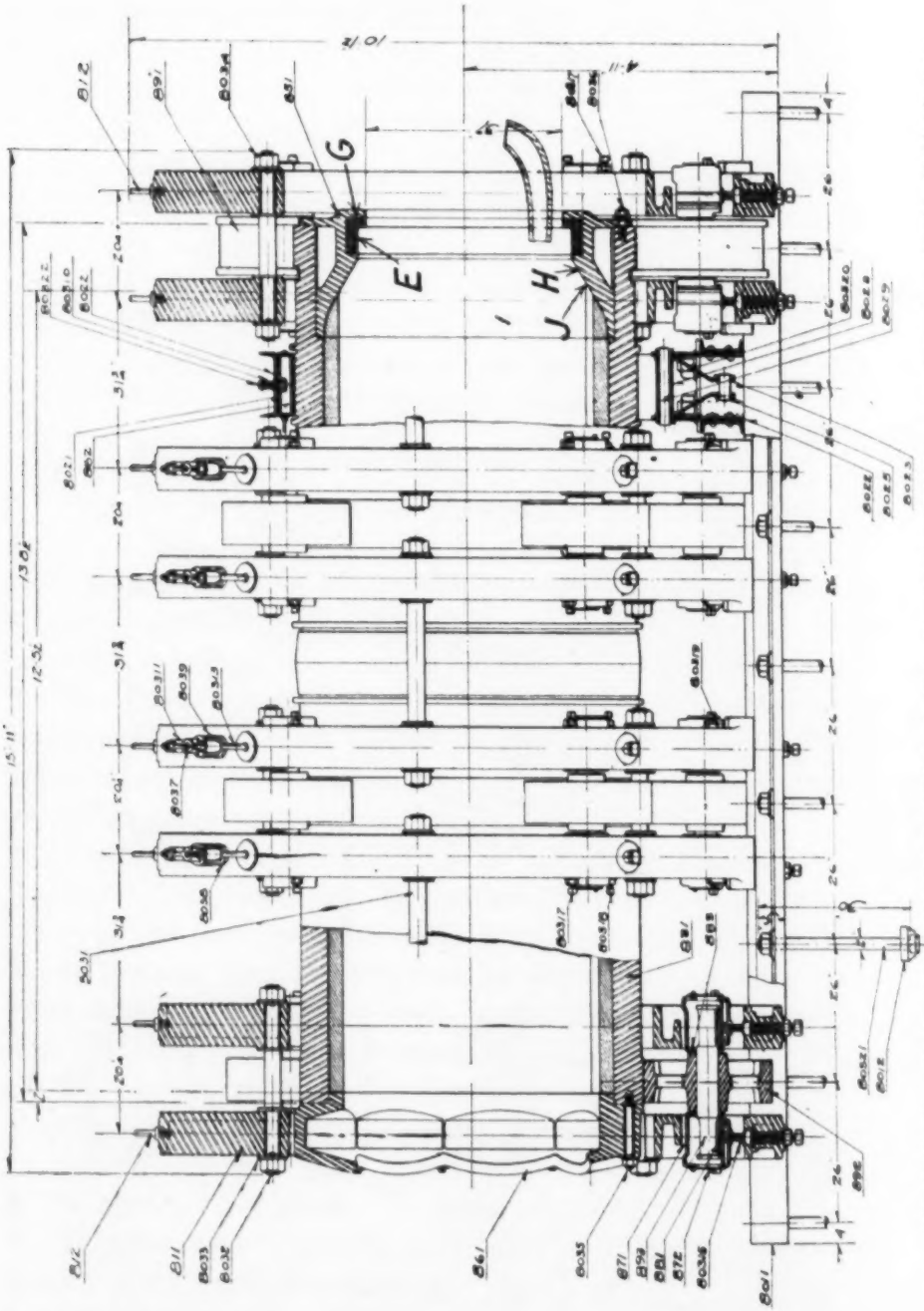


Fig. 3—Centrifugal Bar Casting Machine, Section Through Vertical Plane Along Axis of Rotation (Inside Mold Diameter 53.5 Inches).

the partition lugs and broken up into a fine spray. This spray instantly chills in the air and comes down into the metal in the form of shot. Some of this shot is remelted and re-incorporated into the metal, some of it is not. The result is that when the bar is rolled, the cold shot is knocked out and holes are left in the

rolled product. Some years ago at the works of a certain electrical company, bars were made by this process. After casting they looked fine, but when rolled out into sheet the product had more the appearance of a screen than of sheet.

This difficulty has been overcome in the Cammen process (the writer begs to apologize for the use of his name in this connection, but cannot help doing so, as practically the entire work in the development of the bar casting process within the last five years has been done by his own organization and incorporated in patents issued in his name) by the construction shown in Fig. 3. The metal is teemed against the smooth-walled, restricted neck E of the mold; here the metal is picked up by the rapidly spinning mold and pressed by centrifugal force against the wall of the mold. It cannot get out of the mold, because of the presence of the collar G, and therefore has to go the other way. It is thus forced down over the shoulder H, gaining in centrifugal force as this is done, because of the increase in diameter. By the time it reaches the beginning of the partitions at J, it is already spinning at the same rate as the partitions themselves. There is therefore no relative motion between the two and no blow, the metal generally flowing around the shoulders of the partition lugs and filling the spaces in between. This is what is actually happening in the machines and resulting in the production of bars absolutely free from cold shuts. The use of this device at the end of the mold, called "bottle neck" is one of the characteristics of this process. Equivalent designs have been developed and covered by patents. The only one, however, which is believed to have a real production value is the one shown in Fig. 3.

Fig. 3—Centrifugal Bar Casting Machine, Section Through Vertical Plane Along Axis of Rotation (Inside Mold Diameter 53.5 Inches).

Mechanics of Centrifugal Bar Casting

Let us see now what happens when bars are cast and why this process is believed to have a metallurgical and technical value. In contradistinction to centrifugal tube casting, centrifugal bar casting permits the handling of large amounts of metal from perhaps 5 or 6 tons for sheet, bar and wire rod molds up to some 30 tons per machine in rail and structural steel billet casting. Because of this a close control can be had on the rate at which molten metal is delivered to the spinning mold. As the first metal comes in it instantly freezes, probably close to the beginning

of the partition lugs. The next metal, however, flows a little way over the hot metal previously solidified, rather than over the cold wall, which gives it a chance to reach further out into the mold and really produces an equivalent of tube casting in a hot

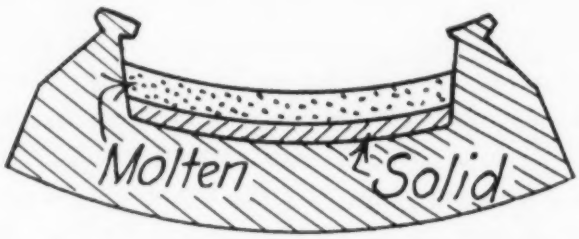


Fig. 4—Diagrammatic Illustration of the Process of Freezing of Centrifugally Cast Bars.

mold. In this way from the first metal teemed from the ladle a thin layer is formed the full length of the mold, which may be anywhere from 6½ feet to 14 feet and more long. As the next metal comes in, it is flowing over the layer of extremely hot metal which has just solidified. It is important to teem the metal from the ladle into the machine at such a rate that at no time should there be a layer of molten metal present of a thickness greater than say ¼ inch. Fig. 4 shows diagrammatically an original solidified layer of metal in immediate contact with the mold, and the next layer thereon which is still molten. As will be made clearer later, the rate of teeming is one of the most vital influences affecting the structure of the cast bars.

Now a continuous process takes place. As more molten metal is added at the top of the layer of molten metal already present, the bottom of this layer solidifies and in this way the thickness of the solid layer is increased while that of the molten layer stays approximately without change. This has several results. In the first place the solidification of the metal proceeds at a fast rate so that roughly not more than 30 to 45 seconds, and possibly much less, elapses between the time the metal leaves the ladle and the time it solidifies in the mold. Compare this with, say, 15 minutes to ½ hour that the same process takes inside of a 3-ton ingot under the usual practice. It is this very great rapidity with which the metal freezes that makes it practically impossible for segregation to take place.

In an ordinary ingot, freezing proceeds in the following way. The shell of the ingot rapidly freezes all around while the

central core remains molten for a long time. As the metal freezes it contracts and as the freezing proceeds from the outside of the shell inward, a contraction takes place in the shell while the central part of the ingot is still liquid. When the ingot finally freezes, a series of planes of weakness are formed which in a rectangular ingot are directed roughly along the diagonals of the horizontal section. The larger the ingot the greater and more dangerous are these planes of weakness. Without going into detailed discussion of their origin which is well known, it may be said that the most essential condition for the formation of such planes of weakness in an ingot is availability of time. In centrifugal casting no such time is available, and hence the most important condition is removed, so that "ingotism" becomes impossible. Furthermore, the freezing proceeds in thin layers and the metal while freezing is perfectly free to draw from the molten layer present at its top until the final layer is being formed. Because of all this, centrifugally cast bars have been found to be absolutely free from such planes of weakness as are encountered in stationary ingots.

Elimination of Gases Contained in Molten Metal

When we come to the matter of gases, a somewhat more complicated condition is found to exist. All molten steel contains a certain amount of gases held in solution. As the metal chills, its ability to hold the gases decreases and a liberation of gases takes place. This action is extremely rapid and will take place even during the short period of freezing available in centrifugal bar casting. As the temperature of the bottom of the molten layer decreases from that at which it reached the bar initially to that of freezing, the metal liberates gases which gradually accumulate in the molten layer maintained on top of the bar by flow from the ladle. The ability of this layer to hold the gas in solution is, of course, quite limited, so that after a while a discharge of the gases from the metal into the air takes place and the topmost layer may be considered in the light of a saturated solution of gases in question in the metal. As long as new metal is supplied to the bar this condition will be maintained more or less stationary. It is only when we come to the topmost layer at the end of the casting that we have to consider what happens to the gas dissolved in the metal. The answer de-

pends on the rate of freezing of the topmost layer and on the velocity of rotation of the machine. If this topmost layer is thin, metal being supplied from the ladle at a comparatively slow rate (more will be said about it later) only a comparatively thin layer of the ultimate metal structure is at best affected by the presence of gases, even should the metal freeze in such a manner as to prevent their possibility of escape. In that layer, however, the gas liberating from the metal may be unable to escape and small blowholes may be formed. The question of speed at which the machine is run becomes of importance here.

The centrifugal force exerted on the metal during spinning varies as the square of the number of revolutions, let us say per minute, so that if the "factor" at 200 revolutions is 4, the factor at 300 revolutions becomes 9, etc. The higher the speed the greater will be the pressure of the metal outwards, and the greater will be the tendency to force out all gases as they form towards the innermost layer and thus possibly out of the metal entirely. As a matter of fact, some interesting tests were made in a demonstration machine of small diameter and hence running at comparatively high speeds. Bars were cast some 6½ feet long, 4 inches wide and about 1½ inches thick, the purpose of such a test being to determine the most difficult conditions under which the process can be applied, the combination of considerable length of bars with their small cross-section being, of course, such as to make the application of the process most difficult.

When the machine was run at 900 revolutions which gave a factor of 8.1, and low carbon (0.09 to 0.12 per cent) effervescent steel was teemed, the outside layer of the bars was found to be quite good, but the inside layer to a depth of about ½ inch was full of blowholes, some of them more than ¼ inch in diameter. The speed was then raised to 1100 revolutions, giving a factor of 12.1 or about 50 per cent higher than before. The change in the character of the section of the bar was extremely interesting. In many places the porosity disappeared completely, the bar being solid throughout. In other places some porosity still remained, but it extended to only about ⅛ inch from the innermost face of the metal and the blowholes were now small. The frame of the machine was not strong enough to permit operating it at 1200 revolutions which would give a factor of 14.4, particularly as

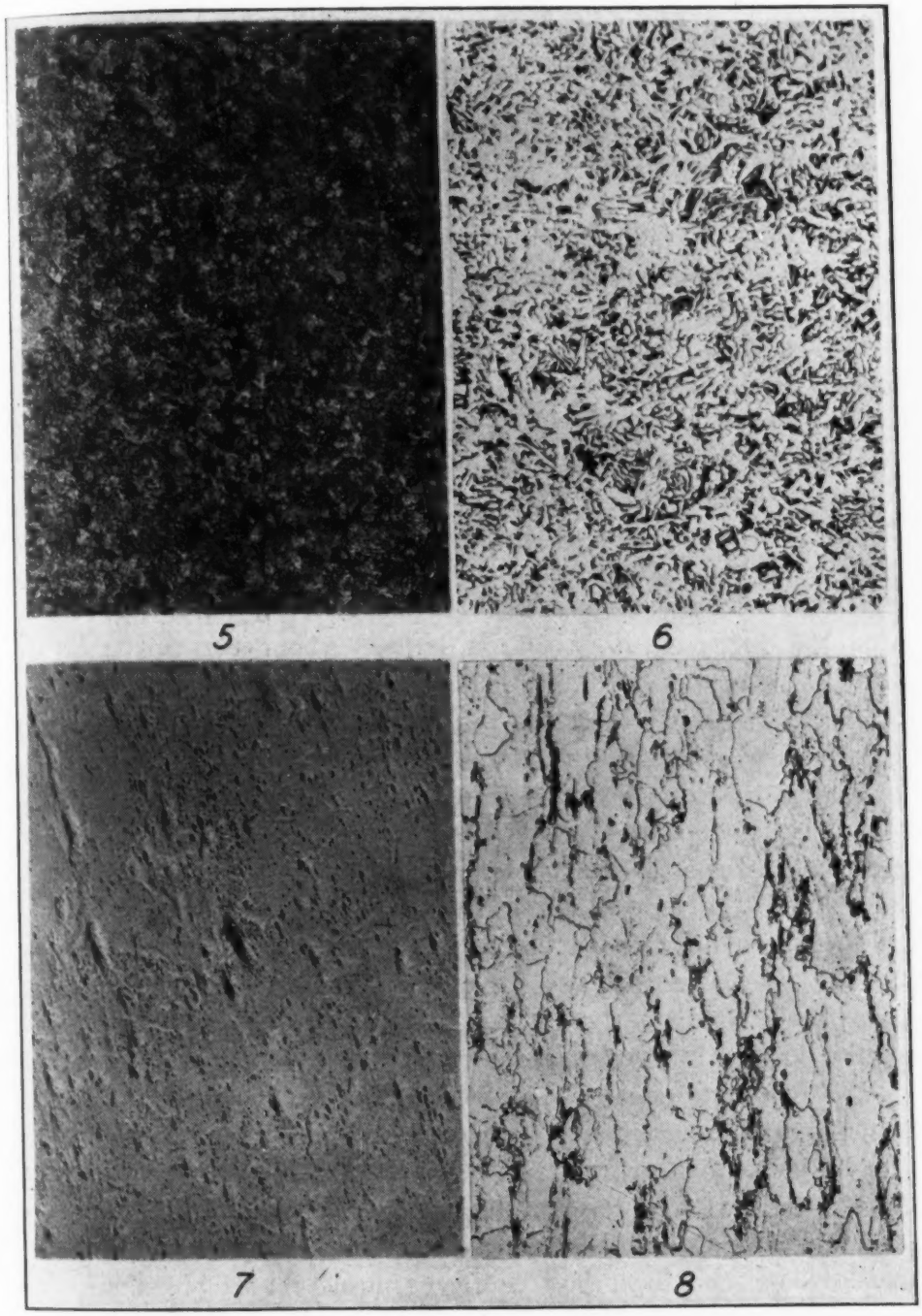


Fig. 5—Structure of Centrifugally Cast Bar of Ball Race Chromium Steel, 1.10 per cent Carbon, Annealed but not Worked. Fig. 6—Structure of Strip Rolled from Centrifugally Cast Bar (Reduction in Rolling 1 in 6). Fig. 7—Structure of Centrifugally Cast Bar (79.5 by 4 by 1.5 Inches) Improperly Cast. Note Dirt Inclusions. Fig. 8—Photomicrograph of Sheet Rolled from the Type of Bar Shown in Fig. 7. (Hot Rolled, Blue Annealed, Pickled and Terne-coated).

sufficient information was believed to have been obtained from the runs at 900 and 1100 revolutions per minute.

Structure of Centrifugally Cast Bars

Many tests on centrifugally cast bars have shown that the structure of the metal is intermediary between that of the average ingot and that of a forging. Fig. 5 shows the structure of a centrifugally cast bar properly made. Fig. 6 shows the macrostructure of a strip rolled from one of the bars made at the same time as the bar shown in Fig. 5. Although very little rolling work has been done on the metal (a reduction in thickness of about 1 in 6), and that in a very light mill, no lines due to ingotism are present. On the other hand, Fig. 7 shows a centrifugally cast bar made experimentally and not under the writer's supervision by people who ought to know better but did not, and is shown here merely to illustrate some of the troubles that may occur when centrifugal bar casting is not applied properly. In this case, effervescent steel (0.12 per cent carbon) was teemed from the furnace into a 50-ton ladle. About two-thirds of the ladle was then poured off into ingot molds. Next, a small auxiliary ladle was filled from the big ladle, and this was teemed into the centrifugal casting machine. It is obvious that in pouring the metal from the big ladle into the small ladle, all the dirt and loose clay in the latter was washed into the metal; the latter was also very viscous as the metal was quite cold in the big ladle by the time three-quarters of it was poured off, and was still further chilled by being poured into the small ladle. As explained above, centrifugal force alone will not get rid of dirt under such conditions, and this is well illustrated by the flecks of dirt visible in several places. Centrifugal bar casting is not a cure for dirty steel or an excuse for poor practice. Fig. 8 shows a photomicrograph of sheet rolled from centrifugally cast bars only 1.5 inches thick. It is significant for two reasons. In the first place, effervescent steel was used in casting the bars, and no blooming could of course be done on such thin castings. Nevertheless, the sheet is free from porosity and blowholes. In the next place, only little work could be done on the metal in the rolling, and yet the structure of the rolled sheet is by no means inferior to that made in a conventional way from big ingots. It is important to remember, however, that centrifugally

cast bars are not intended to be used as final products, but merely as material for rolling and forging.

In speaking before a body of experts, such as represented by the American Society for Steel Treating, it is unnecessary to explain formation of pipe in an ingot. The recognized theory today is that it is due in part to evolution of gas on freezing, essentially in the manner described above, and in part, to the fact that in an ordinary ingot the external surface solidifies first, and the core last. The volume of the ingot is, therefore, determined on the solidification of the shell and when the core solidifies and contracts it can only do so at the cost of forming a cavity. This can be prevented in part by such methods as hydraulic compression of ingots, which, however, are not applicable to the great majority of steel products. Another method widely resorted to is the use of dozzles or hot tops, but this means only transferring the pipe cavity from one part of an ingot to another. In centrifugally cast bars the same process takes place. As the bottom layer solidifies it contracts and if left alone would form contraction cavities. There is, however, an overlying layer of molten metal powerfully pressed against the solidifying lower layer, and this serves efficiently to fill up contraction cavities. It is only the last layer of metal that has no such source of molten steel to help it out, but here contraction is limited to only a thin strip, probably not more than $\frac{1}{8}$ of an inch, and such contraction cavities as may occur are apparently too small to be noticed. On the other hand, if metal is teemed into the mold too fast, and particularly if too much vibration is present in the mold, the surface is apt to be rough or wavy.

Because of this, in a properly teemed bar, there will be no cavity. Emphasis should be laid, however, on the bar being properly teemed. If the metal is supplied to the mold at an excessively fast rate, a heavy layer of molten metal is present at the end of the teeming. It may (and actually has) happened that the outermost face (i. e., the one toward the inside of the mold) exposed to the cooling action of the air will freeze first, and the inner layer of molten metal next. In such a case contraction cavities will be formed substantially in the same manner as in a stationary ingot. However, instead of lying inside of the ingot, they will all be located at some distance below the inner

surface of the bar. This does not make them any more desirable and the greatest attention should be paid to determining for each size of bar cast, each size of machine, and each speed of machine used, the proper rate of teeming which can be then maintained by using a nozzle of the proper size.

Mechanical and Operating Details

Because of the novelty of the process of centrifugal bar casting something might be said about the details of its application. As stated above, the purpose of centrifugal casting is to provide material for use in rolling or forging. Let us consider the former. Today for rolling, such as, for example, rails, a large ingot is cast, say, 24x24 inches in cross section, some 6 feet long. The ingot is then delivered to the soaking pit and thence to the blooming mill, where it is converted into a billet or slab suitable for the production mills (this term will be used henceforth to cover the roughing and finishing mills). The purpose of centrifugal bar casting, on the other hand, is to produce a bar of such a size and character of metal that it would be directly suitable for rolling in the production mills and would give an ultimate product of a quality not inferior to that produced by the ordinary process. This means that the character of the material should be such that the ultimate result would not be affected by the elimination of blooming. The section of the bar should be such as to be directly suitable for use in the production mills and its length should be such as to make the use of production mills economical.

Several considerations are involved here. The first of them is,—Why is blooming required today? Tests made some years ago at the Bethlehem Steel Company on forgings have shown that even if the cross section of an ingot is reduced by forging in the ratio of 64 to 1, which is more than any blooming ever did, ingotism is by no means completely eliminated. On the other hand, blooming in present ingot practice is used for excellent reasons. The ingot as cast today has an extremely variable structure, the metal being fine-grained and strong in the shell which freezes first and does it rapidly. It is coarse, pipy and vitiated by planes of weakness in other parts of the ingot, especially the core where freezing is slow and where it proceeds simultaneously with the development of considerable mechanical strains. What blooming does is, by rolling the metal at practically welding temperatures

and under enormous pressures, to equalize the structure more or less throughout the body of the metal and to eliminate to a greater or lesser extent the weak spots enumerated above. Where, as in centrifugally cast bars properly made, these weak spots do not exist, and where the structure of the metal is fairly uniform to start with, blooming would not improve the metal, and it can be safely eliminated. As a matter of fact, sheet was rolled from bars not more than 1½ inches thick and the physical characteristics of the product were in no way inferior to those of sheet rolled from conventional big ingots. (Fig. 8)

Figs. 2 and 3 show two sizes of machines; one comparatively small for casting sheet bars 53½ inches inside diameter of mold, and 12 feet long, and the other for casting plate bars 90 inches in diameter and 14 feet long. A machine is now being designed for a licensee to cast rail bars 9 inches × 10½ inches × 13½ feet to take 28 tons of metal at a clip; the other two machines taking respectively 6 tons and 17 tons per operation. Not enough practical experience is available today to tell exactly how many machines of each size would be needed to take care of a furnace of say, 120 tons. It is expected, however, that five machines with one standby of the smallest size here shown would be amply sufficient and three machines with one standby of each of the larger sizes.

Rate of Teeming in Bar Casting

As indicated above, the matter of rate of teeming of metal from the ladle is of the most vital importance for the success of the process. As stated above, during teeming a layer of molten metal of not more than ¼ inch should be maintained in the machine, and it may be added that if such a layer could be maintained in an ordinary ingot, the metal produced would be probably as good as when made by centrifugal casting. Centrifugal force, while rendering certain useful services, is not an absolutely essential element to the success of the process apart from help in distributing the metal, and it is the rate of cooling of the bar that contributes the vital share to freeing it from the defects of the conventional ingot. Take an ingot 24 × 24 inches, × 72 inches long. Assume that it takes 20 seconds for a layer ¼ of an inch thick to freeze. It would need then over 1½ hours to teem such an ingot, which is obviously out of the question. Take,

on the other hand, the 90-inch machine shown in Fig. 2. This contains 8 bars which will be described as being, for the sake of simplicity of calculation, 24 inches wide and 14 feet long. In such bars a layer of metal ¼ inch thick represents 2688 pounds so that assuming the freezing at the same rate as above, we get a rate of teeming close to 3½ tons per minute, which is not only perfectly possible but in fact much faster than is done in teeming conventional ingots today. In other words, by laying ingots on a side instead of filling the mold vertically and by providing in each machine a considerable number of bars cast at the same time we succeed in combining a fast rate of teeming from the ladle, which is of advantage from the shop point of view, with a slow rate of building up the ingot (eliminating segregation and ingotism), which latter also means a fast rate of freezing of the metal: an ideal combination, totally impossible when casting large ingots in a stationary mold. The same in a small way is being done in casting small ingots, such as tool steel, by the so-called tundish process, but is not suitable to big ingot casting for several well known reasons.

The metal is delivered to the mold through a spout (Fig. 3) from a conventional ladle equipped with such a nozzle as the new use may call for. The ladle crew is not affected. There is a man on the floor acting as a foreman who watches the metal come into the machine and notifies the ladle crew when to shift to the next machine or stop pouring. By standing in front of the machine and looking into it one can see the metal come in and the bars being built up. Because of the provision of the bottle neck at the pouring end and the powerful pressure exerted on the metal by centrifugal force, there are no sparks of metal flying out at the other end and it is perfectly safe to stand in front of the machine at some distance. At the left corner of Fig. 3 is observed the "gaging head," which is a spillway for the metal. This determines the thickness of the bar cast. As the metal comes in, it gradually builds up in thickness and when it nearly reaches the height of the gaging head the foreman on the floor motions to the ladle crew. It is always of advantage to pour a little over. As the last metal coming from the bottom of the ladle is apt to carry a lot of dirt, it is of advantage to permit in the last pouring quite a little of the metal to run over the spillway. This

will enable the elimination of the dirt from the last teem. This spillway or gaging head is shown in another view in Fig. 9. Metal which overflows into the head forms in the lobes little

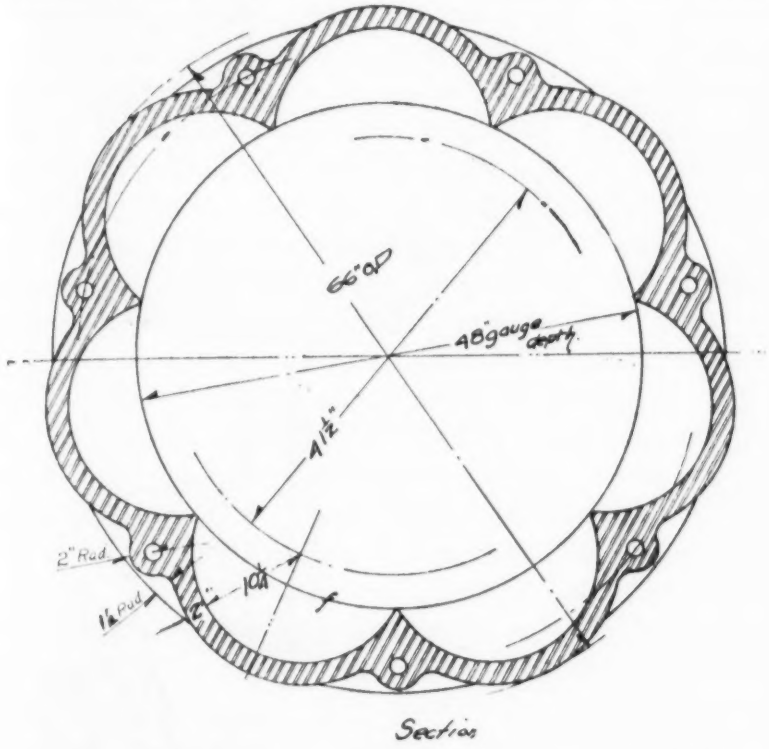


Fig. 9—Gaging Head for Bar Casting Machine (53.5-inch Machine).

castings which are easily shaken out of the head when it is removed for withdrawing the bars and do not stick therein as would a solid ring.

Handling the Cast Bars

We have now reached the stage where bars of proper shape and thickness have been formed in the machine. The next problem is how to take them out. Fig. 10 shows that. As will be noticed in the left part showing a cross section of a mold with the castings, the partition lugs are provided with shoulders. This is an important feature of the mold. Had there been no shoulders on the partition lugs or some similar device, the bars would fall in a heap when the machine slows down at the completion of the teeming; this not only might lead to denting of the surface of the mold by the bars indiscriminately thrown about, but would make their extraction from the mold a difficult and uncertain job.

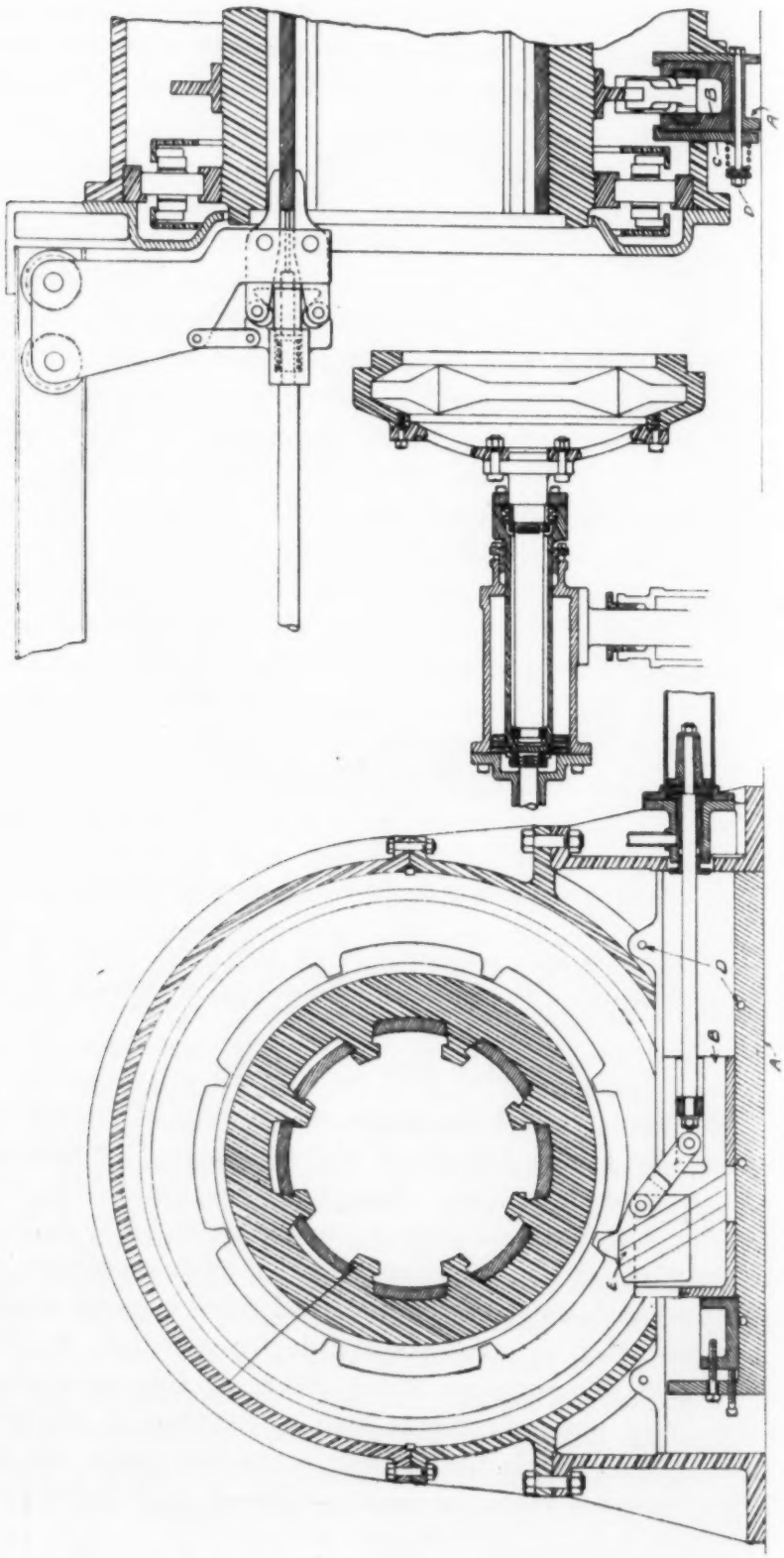


Fig. 10—Various Devices for Withdrawing Cast Bars from Mold.

To avoid this, the lugs are so designed as to permit the top bar (or bars) to clear away a certain distance from the wall of the mold and yet not go far enough to fall out completely.

When the metal has been all teemed into the machine, a brake is applied to the mold rapidly stopping its rotation, and a device (not shown) stops the mold in exactly the position shown in Fig. 10. As shown in the center of that figure the gaging head can be moved horizontally by one hydraulic cylinder and vertically by another cylinder. As soon as the machine stops the gaging head is pulled out of the way sufficiently to leave one or two of the bars on top of the mold free to come out. The pulling device diagramatically shown in the right hand part of Fig. 10 is next brought into operation. This consists of a grab device operated by a hydraulic cylinder so arranged as to engage one, two or more of the bars. As soon as one bar has been pulled out the "mold-stepping device" shown at the bottom in the left-hand part of Fig. 10 is brought into operation turning the mold through such an angle as to bring one or more bars in line with the grabbing device, the bars pulled out being in the meantime delivered to a car or conveyor. The pulling device and the mold-stepping device are so interconnected that one actuates the other and the general arrangement is such that one man in the gallery can operate five machines without trouble by pulling a series of interlocking levers.

Fig. 10—Various Devices for Withdrawing Cast Bars from Mold.

While it is believed that ultimately the operation of the machines will be made so positive and reliable as to permit sending the bar from that machine directly to the production mill, it is proposed today to place a reheating furnace between the casting machines and the rolling mills so as to ensure to the bars a uniform and proper temperature.

Experiments would indicate that a wide selection of sizes is possible as far as the ability to make the bars is concerned. Bars 6½ feet long and 4 inches wide have actually been cast in thickness of less than 1 inch, and, of course, the bigger the bar the easier it is to cast it. Hence, only economic considerations will govern the selection of size of bar, these considerations resolving themselves into the matter of effecting a compromise between the cost of casting and the cost of rolling. Obviously the bigger the bar, the cheaper it is to cast it, but the more passes it requires

in rolling. The lighter the bar, the more expensive the casting becomes, and the cheaper the rolling.

There is one feature in the design of the machine which threatened to cause a lot of trouble, but which has been overcome in a simple manner. This is the question of the partition lugs. It is, of course, possible and may be ultimately found wise to cast the barrel of the mold and the partition lugs in a single piece. In fact, a special design of milling machine has been developed to machine the inside of the barrel and lugs so cast. Careful study of the subject showed, however, that at present any attempt to cast the lugs in with the mold would increase greatly the cost of casting and subsequent machining, and be apt to lead to more trouble in casting the barrel. It must be realized that the barrel in this case may weigh anywhere from 25 to 100 tons and possibly more.

Casting the barrel as a simple cylinder and putting in the lugs afterwards has several advantages. It makes a pattern unnecessary, makes the casting much simpler, reduces the chances of warping, and makes the machining of the inside of the barrel, where a boring mill of sufficient size is available, a comparatively simple proposition. On the other hand, when it comes to casting metal in a barrel with the lugs attached, grave possibilities of trouble begins to loom up. The lugs are slender as compared with the barrel of the mold. They are therefore apt to become heated through contact with the molten metal, more than the barrel, unless the flow of heat from the lugs to the barrel is so perfect as to provide a rapid means of equalization of temperature. Previous experiments have indicated that there can be no rapid flow of heat where two bodies of metal are connected otherwise than molecularly, and that no matter how well two machined surfaces are fitted together the break between them offers a formidable obstruction to the flow of heat. It was therefore to be feared that the partition lugs would become heated faster than the barrel, expand, and tend to warp the barrel, which has enough troubles of its own without this additional complication.

To avoid this the design shown in Fig. 11 was developed. Here the partition lug is deliberately machined so as to leave on both sides a liberal space between it and the barrel of the mold. The lug is attached to the barrel by means of studs and pins

on both sides are provided to keep the lug in position. Metal, preferably iron, is then electrolytically deposited between the partition lug and mold on both sides, the parts on which it is not desired to deposit any metal being painted over with molten

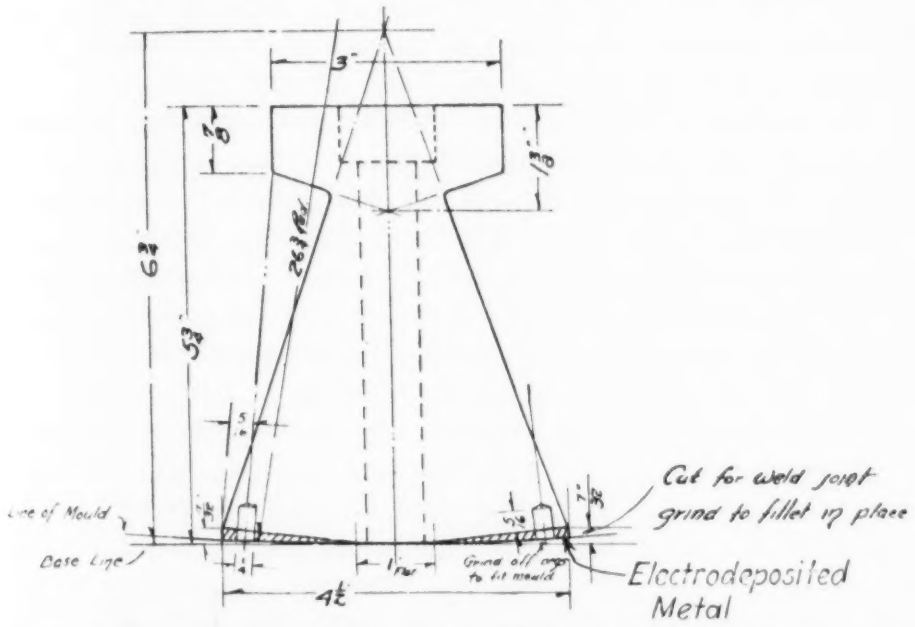


Fig. 11—Partition Lugs and Method of Their Attachment (Showing Good Flow of Heat from Partition Lug to Barrel of Mold is Secured by Electrodepositing Iron).

ceresine. The edges of the lugs are then spot-welded to the mold. While the mechanical strength of electrolytically deposited iron is uncertain this does not matter in the present instance, as the studs are relied upon to hold the lugs in position. On the other hand, such a deposit affords an excellent path for the flow of heat as has been amply proved by experiments. An effort was also made to form a deposit between the lug and barrel of the mold by the Schoop process. This has not led, as yet, to perfectly conclusive results, although there is reason to expect that it may be applied.

Life of Molds

This is an important subject affecting as it does the cost of bars produced by centrifugal casting. It is regrettable, therefore, that not enough information is available to state with authority what the life of the mold would be under given conditions. The rather limited practice in the past has shown that molds are

only little affected even when working under the most strenuous conditions. The following should be taken into consideration in this connection. The molds in bar casting machines are extremely heavy, weighing from 4 to 7 times as much as the metal cast, and the cast bars are removed quite rapidly. Because of this, the mold never becomes very hot, and in fact, it is not desired that it should exceed say 500 degrees Fahr. at any time.

The surface of the molds is carefully machined and the bars, when being pulled out, rub against the shoulders of the partition lugs and not against the barrel of the mold, which is also in favor of a longer life of the mold. The mold material, which is of soft steel, and the circular shape of the mold are so selected as to present the best resistance to cracking due to thermal stresses. There are, however, two sources of trouble to be considered. One is burning out of the mold in spots, possibly at places where in casting the barrel, a small blowhole was formed under the skin. Should this happen, all that is necessary to do is to take the mold out of the machine (Fig. 2 shows how this can be done in a few minutes by loosening the bolts connecting the top and bottom parts of the frames), drill out the burnt spot to uncover sound metal, and deposit electrolytically iron into the bad spot. This method is successfully used to repair erosion in guns, and the huge size of the molds, 50 to 120 inches I. D., makes its application easy.

The other possible source of trouble lies in the possibility of oxidation of the surface of the mold between castings. It is expected that this will be taken care of ultimately by depositing upon the surface of the mold some non-scaling material, and experiments made thus far show a good promise of success in this direction. It has been found, however, that this tendency to scale is not great anyway, and a mold will probably stand at least 1000 castings before it has scaled sufficiently to make trouble. When this happens, the partition lugs may be taken out and the mold rebored.

While this feature of the life of the mold has hitherto received only a somewhat sketchy treatment, it must be remembered that the whole art of centrifugal bar casting is only in its infancy. At the same time it should be borne in mind that it has already attracted the attention of some of the most powerful independent

steel companies in this country. In a process promising to save some $3.00 to $6.00 per ton of steel it would not take long to straighten out such details as protection of the mold against surface scaling. The above estimate of savings is however made for molds not so protected.

Advantages of Centrifugal Bar Casting

The question may be raised as to what are the advantages of centrifugal bar casting as compared with the present method of ingot casting and blooming. Not enough work has been done yet to establish with certainty that centrifugally cast material possesses properties essentially superior to steel well made by the conventional process. It has been found that if the metal is dirty in the ladle, it will be dirty in the casting, so that centrifugal casting is not a cure for poor furnace operation. On the other hand, there is good reason to believe that in properly made centrifugally cast metal segregation will be entirely eliminated or at least greatly reduced. The main value of centrifugal bar casting (and herein it differs materially from centrifugal tube casting) lies however in the stark matter of costs. The reduction of cropping from an average of 12 per cent (running as high as 20 per cent in some special cases, such as rails) to about 2 per cent, and the elimination of the entire blooming operation with all it implies, are equivalent to a reduction in costs of from $3.00 to as high as $6.00 per ton on standard products, as shown in detail in the report of Barton R. Shover, reprinted in part in Appendix I.

This is not the whole story yet, however. A Committee of the American Iron and Steel Institute (Chairman, C. O. Hadly) recently made a report on Quality Classification and Average Extra Cost Above Base of various kinds of steel blooms, billets and slabs. The special requirement in Class SR is that the surface be free from visible imperfections. Centrifugally cast bars, properly made, are free from such imperfections on three sides always, and the fourth (innermost) side can be milled at a cost of some $0.10 per ton, while the average extra cost above base as specified by the Committee is $2.50 per ton.

In Class DR a similar extra of $2.50 is allowed for freedom from piping obtained in ordinary ingots by special top discard.

As centrifugally cast bars are naturally free from piping, except possibly on the innermost face (and this can be taken care of by milling), practically the entire extra goes into extra profit with the new process.

In Class SDR an extra cost of $5.00 is specified for a combination of special requirements of the two classes just discussed. It becomes practically extra profit for makers of centrifugally cast bars, and the same applies to Class F, steel of forging quality. If you add to the above the saving indicated by the Shover report (Appendix I), there will be a difference in costs between centrifugally cast products and those made from ingots cast in stationary molds of the order of $6.00 to $8.50 per ton, an enormous difference in costs for plain carbon steel. This difference in costs, even apart from possible improvement in the quality of products, that would appear to serve as sufficient justification for the development of centrifugal casting.

To existing steel plants the elimination of the blooming mill will not be entirely welcome, perhaps. Few like to think of scrapping $100,000,000 worth of equipment, some of it very new, even if economies are to be secured by such an operation. New mills will however appreciate a cut in initial cost of the order of $2,000,000 to perhaps $2,500,000.

Appendix I

Abstract of Report on the Cammen Process of Centrifugally Casting Blooms, Billets and Slabs, with special reference to Costs.

By Barton R. Shover

The yield from molten steel to finished blooms in the centrifugal casting process is much higher than even the best practice by the present method of casting in stationary ingot molds.

The cost of molds and stools, stripping, also soaking pit and blooming mill operation are eliminated. For these operations are substituted the casting machine, milling the bars and reheating.

Comparison of Costs

The comparison is made on rolling 39-foot 100-pound rails. Costs are based on the A. I. & S. E. E. "Cost and Practice Chart." Blooms are assumed to be 9½ × 9½ inches × 13 feet 3½ inches to produce three 39 foot 100 pound rails with a 30 inch crop on

each end of the finished length. Each machine makes 18 bars per cast.

Weight of rails	3900 lbs.
Weight of crops	167 lbs.
Weight of bloom	4067 lbs.

The Cammen cast bar has a wedge-shaped piece on one end, which must be cut off, also ¼ inch milled from one surface.

Weight of bloom		4067 pounds	
Weights of wedge piece		153 pounds	
Weight of part milled off		108 pounds	
Total weight of cast bar		4328 pounds	
Yield, steel to rails	3900		
	4328	90.1%	
Ingots required for bloom	4067		
	.81 (Yield)	5021 lbs.	
Yield, steel to rails	3900		
	5021	77.67%	
Increased yield over present methods		16.%	

The difference between the cost of ingots and Cammen process cast blooms would be in:

Teeming Labor
Stripping Labor
Floor Labor on Cammen Machine
Molds and Stools
Up-keep of Cammen Machine
Electric Power
Milling the cast bars

Teeming Labor—Less skill is required for both ladle cranemen and steel pourers to teem a ladle of steel into three troughs than into the usual molds, but this is neglected in estimating the labor cost.

Stripping Labor—The Cammen process eliminates this item, but substitutes a pulpit operator of about the same qualifications.

Floor Labor—The machine will require a floor man, which at $10.00 per turn and with 1500 tons per day output, would mean a cost of $0.02 per ton of bars.

Up-keep of Cammen Machine—This is an unknown quantity, but with the exception of the casting barrel itself, the upkeep

should be no greater than that of ingot cars and strippers. The cost of casting barrels is considered under the next item.

Molds and Stools—The average cost of molds and stools is about $0.16 per ton of ingots for conversion and freight only, not counting the cost of the pig iron. The cost of the casting barrel per ton of bars cannot be determined but the following is offered as an estimate.

The barrel is a steel casting 13 feet, 3½ inches long, about 9 feet in diameter and 10 inches thick. It weighs approximately 200,000 pounds and at 10 cents per pound would cost $20,000.00.

There is sufficient metal to allow boring out ½ inch three different times, which means a total of four surfaces for the entire life. The cost per boring would be about $1500.00, and there would be approximately 20,000 pounds removed, leaving 180,000 pounds or 80 tons as scrap. The total cost of the barrel for its entire life would be:

200,000 pounds	@ 10c	$20,000.00
3 borings	@ $1500.00	4,500.00
		$24,500.00
Less 80 tons scrap	@ $16.00	1,280.00
Net cost per barrel		$23,220.00

While the number of heats per barrel is unknown, an analysis of the conditions under which the barrel operates and various factors affecting its life would seem to warrant an estimate of 1000 casts per surface, or 4000 for the life of the barrel is within reason, but assuming 2000, the cost per ton would be:

$$\frac{\$23{,}220.00}{34.8 \times 2000} = \$0.33$$

With experience in regard to the proper analysis of the steel used for the barrel, casting temperatures and methods, there should be a marked improvement in the results obtained with the experimental machine.

Electric Power—Power for operating the stripper would be eliminated, as would also some for the ladle crane. No data are available in regard to these items, but since the total power required for a completely electrified open hearth plant and stripper is 8.4 kilowatt hours per ton of ingots, it is fair to assume 1 kilowatt hour for the stripper and relief of ladle crane.

The Cammen machine requires 1000 horsepower to operate and is in use about 6 minutes per cast, including acceleration.

$$\frac{1000 \times 6 \times .746}{60} = 74.6 \text{ kilowatt hours per cast}$$

$$\frac{74.6}{34.8} = 2.2 \text{ kilowatt hours per ton}$$

There will also be a little power required for drawing the bars, so a total of 3 kilowatt hours per ton of cast bars would be ample, which at the rate of 1 cent per kilowatt hour would be $0.02 more than the cost of electric power for ingots.

Milling the Bars—In the early experiments some of the bars contained blowholes or gas pockets halfway through, but this condition was remedied until none were found in a 2-inch bar more than one-quarter of an inch from the inside face. It is confidently expected that further experiments on the speed of rotation and rate of pouring will entirely eliminate this defect, but because this point has not yet been reached, the assumption is made that the inner ¼ inch of surface is defective steel.

The milling machine considered will finish four bars in one cut at a rate of one foot per minute, or a total time of 13¼ minutes. With proper loading and unloading devices, five minutes should be sufficient interval between milling operations, but assume a total of 20 minutes per four bars, or 12 bars per hour.

A wage of 80 cents per hour for the operator, with a like amount for power, tools, repairs, etc., should cover operating costs. The milling cost per ton of *finished blooms* would be:

$$\frac{\$1.60 \times 2240}{12 \times 4067} = \$ .0734$$

Milling removes 108 pounds from the bar, and 90 per cent of this, or 51 pounds per ton of finished blooms, can be assumed as scrap recovered. The cropped wedge end weighs 157 pounds or 86 pounds per ton of blooms, all of which can be recovered.

It is impossible to produce an exact weight of steel per heat from an open-hearth furnace and as a consequence there is an average of about one ton per heat more than the amount required. With the Cammen Process, if the heat is "short" the bars in the last machine would be of less than the required section and therefore

Cost of Rails

	Ingots	Cammen
Materials	$22.29	$22.29
Electric power	.06	.08
Molds and Stools	.16	.....
Casting barrels	.....	.33
Miscl. items	3.68	3.68
Department labor	1.53	1.55
Total	$27.72	$27.93

become scrap. For this reason, the heats would probably be made "long", a fair estimate of the amount being 10 per cent of the last cast, or 3.5 tons per heat.

	Ingots	Cammen
101% Steel	$28.00	.....
103.5 Steel	.....	$28.91
Less 22.4 lbs. scrap @ $16.00	.16	.....
Less 78.4 lbs. scrap @ 16.00	.....	.56
Cost of steel	$27.84	$28.35
2765 pounds Ingots @ $27.54	$34.36	.....
2383 pounds Bars @ 28.35	.....	$30.16
Heating & rolling	2.31	.....
Milling	.....	.07
Heating	.....	.55
	$36.67	$30.78
Less 464 pounds scrap @ $16.00	3.31	.....
Less 86 pounds scrap @ 16.00	.....	.61
	$33.36	$30.17
Less 51 pounds scrap @ $12.00	.....	.27
	$33.36	$29.90
4067 pounds blooms @ $33.36	$60.57	.....
4067 pounds blooms @ 29.90	.....	$54.29
Less 167 lbs. scrap @ 16.00	1.19	1.19
	$59.38	$53.10
Cost per gross ton	$34.10	$30.50
Rolling & finishing	4.86	4.86
Cost of rails per ton	$38.96	$35.36
	35.36	
Saving by Cammen Process Per Gross Ton		$ 3.60

The above comparison of costs, neglects, seconds and rejects, which should be less for the Cammen Process because of the lack of segregation, omission of blooming and absence of pipes. If

the yield of salable rails only were considered, the difference would be even more marked.

There is nothing new in the equipment used by the Cammen process as everything has been used for the same or similar work, therefore changes in application should be neither difficult nor expensive. Practically the only questionable point is in regard to the cost per ton for casting barrels, and even if this cost should be found to be considerably in excess of the estimate, the large difference in the final cost seems sufficient to provide for any excess cost of casting barrels.

Appendix II.

Unites States Patents on Centrifugal Casting.

A list of the U. S. patents on centrifugal casting up to 1922 has been given in Appendix No. 2 to the present author's paper Centrifugal Casting, published in *Transactions* of American Society of Mechanical Engineers, vol. 44, pp. 261-293. The present list comprises the patents issued since then, as well as a few additions to the list previously published.

1,375,826	1,477,508	1,513,747	1,546,011
1,398,008	1,477,872	1,514,129	1,549,124
1,399,252	1,479,629	1,514,319	1,550,126
1,400,857	1,480,000	1,514,320	1,553,029
1,415,421	1,480,107	1,515,544	1,551,590
1,417,938	1,480,179	1,515,953	1,553,136
1,418,826	1,483,372	1,517,579	1,554,476
1,425,927	1,485,592	1,517,608	1,556,291
1,427,508	1,485,859	1,517,609	1,559,779
1,428,048	1,485,860	1,520,749	1,560,953
1,429,807	1,486,544	1,521,244	1,562,029
1,433,763	1,486,951	1,521,634	1,563,151
1,436,305	1,486,952	1,523,021	1,565,007
1,444,953	1,486,953	1,527,338	1,567,488
1,445,385	1,489,032	1,527,729	1,573,089
1,450,552	1,489,036	1,528,303	1,580,437
1,452,480	1,490,589	1,532,537	1,581,169
1,452,838	1,492,091	1,532,202?	1,581,635
1,457,040	1,496,429	1,532,690	1,581,790
1,457,834	1,498,138	1,533,780	1,582,601
1,465,153	1,498,562	1,535,017	1,583,486
1,466,826	1,500,428	1,535,330	1,583,576
1,467,496	1,500,707	1,535,610	1,584,840
1,469,206	1,501,337	1,538,585	1,594,336
1,469,242	1,501,338	1,539,691	1,595,119
1,471,052	1,502,435	1,540,558	1,600,904
1,475,996	1,503,122	1,542,810	1,602,426

DISCUSSION

DR. H. W. GILLETT: A good many people connected with the alloy steel business have a more or less expressed or unexpressed feeling that the tonnage steel maker is not particularly interested in improvements or in progress. That, of course, is certainly not true in cases where any cheapening of the process can be brought about. It is encouraging to note signs that lead one to think that in time some tonnage plants may be equally eager for an increase in quality.

The particular type of work recorded in this paper requires a rather unusual combination of experience, and it seems that such a process must necessarily be handled by those who have a very complete understanding of the phenomena involved in the manufacture and distribution of steel. A large metallurgical background is required, and the other part of the picture is the overcoming of the mechanical difficulties, and it is quite natural that a man who is both an outstanding mechanical engineer and a metallurgist should be the father of this particular development.

G. A. DORNIN: It seems to me that, basically, centrifugal casting is a process that substitutes centrifugal force for the force of gravity, centrifugal force being, if you wish it, a much greater force, and any benefit you obtain in the casting of steel using this greater force you will derive from the centrifugal method. Any defect that is intensified by this greater force will be obtained in a correspondingly greater degree.

Mr. Cammen said that segregation was entirely dependent on the rate of freezing. I think that segregation is dependent on the rate of freezing and the force of gravity; the rate of freezing governing the rate at which the dendritic branches grow and which tend to entrap the segregates before they can move. The faster this is made to take place, the less the segregation. Gravity, on the other hand, tends to let the lighter segregates rise and the heavier particles either stay where they are or possibly fall. On that basis, other things being equal, I feel that segregation will increase in centrifugal casting in direct ratio between the force of gravity and the centrifugal force that is used.

It seems to me that the best comparison you can make between the centrifugal bar casting method that is suggested here, and ingot teeming, would be the casting of horizontal ingots. I think there is no question that if steel is poured slowly enough, one can almost eliminate segregation. The only practical difficulty has been to pour it slowly enough. If one could pour a 50-ton ingot at the rate at which that ingot freezes, there would be no segregation and no shrinkage cavity, because that would be automatically compensated for as the shrinkage took place. But practically we do not find that we can do that.

I think there is another side to the possible casting of steel bars and billets, and that is the fundamental difference between castings and forgings. An ingot is a casting, and as far as the research has gone under the very best possible conditions, there are interstices, or seem to be interstices between the crystals. These are probably closed in rolling. We have never yet been able to roll ingots directly into a product. The nearest approach to

this is in the piercing of round ingots for large seamless tubes, a comparatively new art—at least in this country—and we do not yet know how successful it is going to be.

My own opinion is that in heating, unless the heating is carefully done, we obtain a saturation of ferrous oxides along the crystal boundaries, or possibly into these interstices that I have just mentioned, and once having that iron oxide in those spaces, welding cannot take place.

The present day practice is to heat the ingot as carefully as possible, and roll it to some intermediate form and then shape it to its final commercial form. This method gives an opportunity to chip out surface flaws that develop in that part of the process. As far as I know, having once rolled or worked a piece of steel, these surface flaws do not again occur except in extreme conditions—I am speaking of a piece of steel that has been made from a reasonably sound ingot—so that I think those two things are going to be controlling factors in the possibility of casting billets, casting the size of billets that is wanted directly, and rolling that fo the desired shape.

DR. H. W. GILLETT: It seems to me that we have a few other factors to take into consideration in the difference between the ingot and the bar. In the case of the centrifugal bar you are casting essentially a very much smaller ingot and getting very much more rapid freezing. Now, when one desires to sample a piece of steel and avoid segregation so that his sample for analysis will represent the average or the integrated content of the whole, he generally pours it into a very thin mold so it will freeze as rapidly as possible, thereby preventing segregation on any large scale, so that segregation, if present, is negligible within the amount that is taken for the sample. And as regards the shrinkage, of course, it is perfectly obvious that you cannot overcome shrinkage, but is it not a purely mathematical question in the case of casting a rather thin, flat ingot of this sort, that the shrinkage takes place in a very shallow, truncated cone, whereas in the ingot the trend is to have it in a deeper cone, and the amount that must be eliminated to get down to the bottom of that is a question of speed of solidification and the size of the ingot. I should think that if we are to make a very direct comparison between this method and the existing methods, one would have to compare the casting of rather small ingots instead of very large ingots.

W. J. MERTEN: I would like to ask the speaker a question, whether the synchronizing of the stream of metal with the speed of rotation of the machine is very close or whether there is a very large margin of safety so that the two do not need to be very nearly of the same speed? Also whether it has any effect on the quality of the material obtained.

LEON CAMMEN: The measure of speed is one which can vary widely. It is necessary to have a certain minimum speed, and there is a factor of safety of possibly 40 per cent. So that if this speed is raised above that, no harm is done; if the speed is lowered below the required limit certain troubles such as piping and so on.

The matter of delivery of metal is the most vital one, and I will speak

of this more fully in answer to Mr. Dornin. It must be controlled definitely for any size of machine.

EMIL GATHMANN: I would like to ask the speaker a question as to the sizes which he has actually experimented with, whether they are just little flat plates or actual billets. There is quite a difference in making a flat plate —I will grant that a flat plate an inch or two thick and five or six inches wide and any conceivable length could be made quite sound by the process as illustrated in this paper, but in the making of a billet, say, 10 by 8 and any particular length, I am practically satisfied that the central zone of that would be depressed just as it would in any ordinary ingot, and that we would have at least one-third of imperfect metal due to shrinkage cavities. The author does not state in his paper whether they were just thin shells that were being made or whether they were actual ingots. In other words, one can pour steel on any iron plate and get a very nice piece of sound steel of very medium thickness, but to begin to build up a billet of, say, 10 by 8, and 12 feet long, as the speaker has stated and has described in his paper, is quite a different problem. One would undoubtedly get a depressed area. I have not gone into it very carefully at this time, but I would say off hand that at least 25 to 30 per cent of the central zone of such a billet would be depressed, piped or spongy. Irrespective of how rapidly it solidifies, it would be the last portion to solidify, and that part would show a depressed area. I notice that Mr. Cammen stated the inner surface is to be milled for a quarter of an inch, but I figure that is far too little on any bloom thus cast. In an 8 by 10 bloom, for instance, I feel that the free inner surface would have to be milled at least 3 inches. That is my own impression from seeing thousands and thousands of ingots. I am speaking of degasified, practically finished steel, not of gassy steel, because gassy steel cannot be made sound and homogeneous, in our opinion, by any method, centrifugal casting or otherwise.

LEON CAMMEN: I want to answer first in connection with Mr. Dornin's question, but before I do that I would like to ask the speaker a question. He said any conceivable length, speaking of ingots about an inch or an inch and a half thick. Just what do you consider should be the depth?

EMIL GATHMANN: The rapid solidification occurs in any mold in the skin solidification, half an inch or an inch, which is practically the metal as it was received from the ladle. After that the freezing is selective and segregation occurs, and if you would stop right off at that point there would be some little depressed area. I have seen ingots only 10 inches high with a depressed area of 50 per cent.

LEON CAMMEN: Well, I will answer that in connection with Mr. Dornin's question, if you do not mind.

G. V. LUERSSEN: I would like to ask the author two questions. The first has to do with the degree of superheat required. That point I should think would be important, and it would be interesting to know just how many degrees Cent. superheat is required in pouring.

The second question has to do with the building up of these ingots, and I should like to ask in that connection whether any precautions have been taken to prevent inclusions due to the oxide film always present on a molten

stream of metal. In this connection I should think that difficulties might be encountered in teeming steels of the high chromium type.

LEON CAMMEN: I can answer that readily. As to the superheat, the steel should be cast as cold as possible. In the work which we have done we have poured off three-quarters of the ladle into ingot molds, and cast in a centrifugal machine from the last quarter in the ladle.

You cast your ingot with the steel as cold as possible, and it is very easy to cast cold steel in this case, because of the fact that in this machine it is possible to use a much bigger nozzle on the ladle than the casting.

The machine which we are building now will take about 12 tons of steel, and we are going to use a nozzle that will permit us to pour off at the rate of four tons per minute, so that we can hold the steel in the ladle longer before we start casting, and we are going to cast very cold steel.

The oxide that forms in the stream will float up on top and form layers on the face of the ingot. The layer, however, is very thin and it would form anyway in the ingot.

Pouring off part of the ladle was done because it was desired in the test period to cast the metal as cold as possible, it being obviously more difficult to fill the rotating mold with cold metal than with hot. In actual operation steel can be cast much colder than now because of the use of bigger nozzles and faster teeming from the ladle. The machine which we are now building will take about 12 tons of steel, and will be filled at the rate of about 4 tons per minute. Because of this, we propose to hold the steel longer in the ladle before starting pouring, and are going to teem what would be considered today very cold steel.

As regards inclusion of oxides, attention may be called to the fact that most of our work was done on effervescent, sheet bar type, steel which is notoriously heavily oxidized when in the ladle, and yet the cast billet shows a solid uniform appearance (except for a thin layer on the innermost surface). There will be a certain amount of oxidation of the metal in the mold, but as soon as a thin layer of oxide has been formed on the surface, it will float on top of the forming billet and protect the rest of the metal from further attack.

We have not cast high chromium steel in bar form, but we did cast it in tube form, and no special tendency towards oxidation was noticed, except on the innermost surface where a peculiar flowery structure, greenish in tint, was observed.

E. F. CONE: Mr. Chairman, I understood Mr. Cammen to say that three-quarters of the metal in the ladle is poured into the ordinary ingot and the rest in the casting machine. Is that correct? Would that be the general practice in carrying out this process?

LEON CAMMEN: That was in an experimental unit.

EMIL GATHMANN: I would like to supplement my remarks. In the rate of freezing, I cannot conceive of there being any increase at all in it due to centrifugal casting. It is merely a matter of being able to distribute the metal in a number of small ingots. The rate of freezing would be the same as it ordinarily would be, and as shrinkage and segregation are directly

proportional to the rate of freezing, according to my contention, I cannot see that there would be any difference in casting in an open, horizontal mold or in the centrifugal casting apparatus, so far as segregation and solidification are concerned. You simply have distribution of the metal in a number of molds so that you are getting rid of your heat, which is necessary. It cannot be held beyond a certain time.

The speaker has stated a very fundamental requirement, the controlling of the rate of pouring. This I have found is one of the most difficult phases of the art. If we set out to pour two tons per minute, sometimes it is only a ton and a half; other times three tons. It is a matter of fact that the state of the art has not yet adjusted itself so as to be able to determine the exact rate of pouring, a matter that requires a great deal of further attention, and we have already given it a lot. We have not been successful in establishing any definite rate of pouring in ingot making.

DR. H. W. GILLETT: A rather interesting suggestion was made by a man who was in my office a few months ago. Obviously the suggestion has not been put in practice, because of practical difficulties, but the theory was that if you could freeze uniformly from the bottom up without having greater radiation from the sides, then instead of having a depression you will compensate for your final shrinkage, and it would be flat on top. The way he was going to do to beat the game was to have a ladle with a hole in the bottom, and that would let the metal drip out, run out on to some sort of a stool which would be pulled down slowly through a suitable cooling medium, and the cooling would progress just as fast as the thermal conductivity of the material would allow it to progress. Meanwhile his ladle was to be heated to hold it at uniform temperature, and the metal was to come out into a continuous bar casting, and there could not be any segregation or any shrinkage.

I think that theoretically, if one could control the rate of cooling around the edges of an ingot he could obtain an ingot without any pipe in it at all, and that, as I take it, is what Mr. Cammen is attempting to approximate as closely as the laws of mechanics will allow him to do so.

EMIL GATHMANN: Mr. Chairman, that is absolutely my idea but you would have a surface that you could not use, in my opinion, if you do that. You would not get a good shell of ingot by the surface conditions, which are really as important as the interior in many cases.

DR. H. W. GILLETT: Of course, there is another point that enters into the problem, and that is in regard to the size of the casting desired. The size of the ultimate object to be made will regulate that. If one is to make sheet, there is no particular reason, provided enough work can be put on the ingot to make the sheet of the desired structure, for starting way back with a big ingot or a big bloom. Obviously one could not make a crankshaft for an ocean liner out of these small bars. Consideration must be given as to what the final product is going to be.

EMIL GATHMANN: There is just one more question I would like to ask, Mr. Chairman.

What has been the weight of sections cast, up to the present time? I

would like to ascertain that so as to know about how it would work for making sheets in one mold.

LEON CAMMEN: Answering Mr. Dornin's question and your questions, Mr. Gathmann, together, because essentially they are along the same line. In the first place, the application of centrifugal force inside the centrifugal machine has absolutely no influence on the rate of freezing. The centrifugal force is simply a mechanical means to attain something. If we could squirt the metal, say, out of a fire hose we would get exactly the same results as we are getting by centrifugal force. The only thing is, centrifugal force is more practical and economical than a fire hose.

Now, the rate of segregation is primarily controlled by the rate of freezing. Segregation means simply that there is more of certain material, sulphides and phosphides and so on, in one part of the ingot than there is in another part. The fact that there is not quite as much in one part as in another part is because the cooling of the metal effects a selective distribution of certain constituents having a lower melting point than either ferrite or cementite. If one could cast a 64 by 64 inch ingot and succeed in having the whole ingot cool at the same rate, there would be no segregation. It is because in the ingot the outside cools faster than the inside that we gradually reduce the ability of the metal to hold certain materials in solution, and displace them gradually toward the parts of the ingot which are still molten. This is the process which results in segregation. Now, the action of centrifugal force will either increase or reduce segregation, depending entirely on whether time is available for it to take place.

Thus, Mr. Langenberg is casting very heavy tubes, several inches thick, in a clay-lined mold. There he holds his metal in a liquid state for probably half an hour, and gets the most beautiful case of segregation, much more pronounced than you get in any of your ingots. Mr. Dornin was perfectly right, therefore, in saying that where the conditions were favorable for segregation, centrifugal force would make the matter of segregation even more pronounced than it would be in the stationary ingot. And I emphasized this matter in speaking about pipe.

When, however, we come to the matter of bars, we have a different condition. Segregation requires time. Actually there is no such thing as instantaneous freezing even of a drop of metal. Dr. Langmuir in my presence calculated the time of cooling of an ordinary drop of water, and he found that it amounts to a very substantial amount of time, something like a hundredth of a second, which shows that it is not instantaneous. Now, assume that all the metal freezes within not more than 30 second after it leaves the nozzle of the ladle. There you have a condition of such a short time available that the amount of possible segregation can be absolutely neglected. And, as a matter of fact, analyses of our bars have shown that it can be neglected except under certain conditions, if the casting was properly done. The same thing might unquestionably be done by other means, and as Mr. Gathmann remarks, if you poured the ingot slow enough you could get it into the ingot. Now, let us see what "slow enough" means. We control the matter of flow so as to have not more than a quarter of an inch of molten metal present

at any time; we will also suppose that the freezing process will take place in that quarter of an inch of metal within 20 seconds; take the ordinary ingot, say, 24 by 24 by 72 inches high, and apply this principle: If a quarter of an inch freezes in 20 seconds, that will mean four times 20 seconds per inch, or something like an hour and a half per ingot. Now, if Mr. Gathmann can pour an ingot 72 inches high so as to build it up in an hour and a half, he will get as good an ingot as we are getting centrifugally. But he can not do it, not even with a Gathmann mold. The reason that we can do it is this (due to mechanical construction): In the first place we pour the ingot on the side and not upright. In the second place we pour not one ingot but anywhere from 10 to 20 ingots at a time. It is the rate of freezing that controls the whole thing, and by using centrifugal force merely as a means for distributing the metal we get this absence of segregation.

Mr. Gathmann made a very interesting remark which I enjoyed immensely hearing. He said, "Of course I am talking about deoxidized steel, not gassy steel. Gassy steel will not work under any conditions." It so happens, however, that most of our work in the machine that we have was done in a sheet mill plant using effervescent steel, and it was done there for the very reason that other gentlemen had the same opinion that Mr. Gathmann has, "that gassy steel could not give a sound ingot without a lot of work being put into it," and therefore it was a good plan to try it out with centrifugal force. We cast our ingots 6½ feet long, 4 inches wide and from one inch to one and one half inches thick. The reason for the selection of this size being that everybody said the metal would not flow 6½ feet long; that it would form a wedge-shaped ingot, and so on. We made all our ingots into sheets directly —and the sheets passed all the physical tests which the regular sheets do.

Now, Mr. Dornin made a remark about the difference between castings and forgings in structure, which again is correct. Centrifugally cast bars are not intended for and should not be used as the final product. They are simply the initial product for rolling, except that instead of starting in the blooming mill we start in the production mill. Actually the structure is intermediary between casting and forging. It is better than an ordinary casting; it is not as fine or as regular as the forging.

Now, as to the matter of pouring, Mr. Gathmann again remarks, perfectly correctly, that the rate of pouring cannot be controlled exactly. You will pour faster through the same nozzle when you have 120 tons in the ladle than when you have the last 25 tons. I do not believe that these small differences will matter essentially in pouring at the rate of four or five tons. When poured at the rate of 2 tons, one half ton represents 25 per cent; when poured at the rate of 4 tons, the same half ton represents only 12½ per cent, and this is not enough to matter.

The whole thing is that we are replacing the casting of a big ingot by the casting of a small billet, and we can in the casting of a smaller billet control the rate of freezing, not absolutely by any means, but to an extent sufficient to produce an ingot which gives good rolling qualities without the heavy work in the blooming mill.

Mr. Gathmann made one remark where I will take the liberty of dissent-

ing with him. He said that if we cast the big ingot, say a 10 by 8, we will get the same kind of a depression inside as we get in an ordinary ingot. Why should we? We have made several experiments to this effect: That we stopped the pouring at a certain point, and we got the thinner ingot with exactly the same structure as the big ingot. Mr. Gathmann admits—tests have shown it anyway—that in a billet 1.5 inch thick there is no depression. Assume that we continue to pour for 10 more seconds, and add another half inch of thickness. This last half inch has, however, come over—at least in part—steel previously solidified, and if the three layers of steel, each half an inch thick, poured first, did not show a depression, why should the last half-inch do so? And if we can cast a billet 2 inches thick without a depression, why not one 10 inches thick? Mr. Gathmann's entire reasoning is based on experience with stationary ingot molds suffering from some irremediable defects, among others, the fact that segregation and such ingot weaknesses as planes of weakness, piping, etc., increase with the size of the ingot, which is due to the fact that the time of solidification of the ingot increases with its size. In centrifugal casting of billets the size of the billet has no influence whatsoever on its rate of solidification, a fact which Mr. Gathmann apparently failed to understand. Any segregation, any depression, any cavities can only exist in this last quarter of an inch. It does not matter whether our ingot is one inch or 100 inches thick; so long as at any place we have no more than a quarter of an inch of molten metal, any phenomenon depending on the solidification of the metal can affect only this quarter of an inch. If we examine the inner structure of the ingot it will be different, I will agree with you. We will get a much coarser crystallization in this part of the thick ingot than we get in the thin ingot. There you would be right. But so far as segregation, contraction cavities and other ingot phenomena are affected, it does not matter how thick this layer is, because this layer is already hard. Therefore I do not believe for a moment that it will matter how thick the ingot is, as far as segregation and contraction characteristics are concerned, only this last quarter of an inch can be affected. That is why, when we consider the possibility of milling, we only consider this last layer of metal.

EMIL GATHMANN: Mr. Chairman, I have one more remark to make. The quarter inch of fluid metal which the author of this paper states should be continually on top of the solidifying mass would mean that there would be a change of rate of pouring continuously during the filling of those molds. The first quarter inch would freeze practically instantly, the second quarter inch or half inch thickness would take possibly instead of one second—two seconds, the third quarter inch would take four seconds to solidify, and when one inch is reached it might take 10 seconds. It would run in a curve that rises upwardly very quickly, so that the last quarter inch would be fluid probably 10 or 20 times as long as the first quarter inch that was placed in the mold. The rate of pouring would change continuously during the pouring of the mold if there was any considerable thickness. I am satisfied that is correct.

LEON CAMMEN: That is partly correct and partly not. It is correct to this extent, that until a layer of some thickness, which we found to be about half an inch, has been formed, there would be this variation: The first metal

freezes, of course, instantly; the next freezes somewhat slowly, and so on. As soon as a layer about half an inch thick forms, the cooling effect of the mold is stabilized, because all flow of heat takes place through this layer. Mathematically there may be some difference between the various layers, simply because the absorption of the heat varies with the temperature of the mold and so on. There is certainly no sufficiently appreciable difference shown by the work done so far.

DR. C. H. HERTY: I would like to ask the speaker just one question on that same idea of thickness. How do you control the rate of pouring so that you always have your quarter inch of metal when you have a much greater circumference in the first quarter inch than you have toward the end of the ingot? That is, for the given quarter inch you have much less metal to pour at the end solidifying at the same rate. You must slow up your pouring somehow.

LEON CAMMEN: This is again a question where I admit I stand corrected. If we have a machine, say, 70 inches inside diameter and pour an ingot 6 inches thick, obviously the quarter of an inch thickness at the beginning will be a few pounds heavier than in the end. However, the difference is so small actually that I do not believe it deserves any attention. You must remember that you have 10, 12—up to 20 bars in the same machine. The amount distributed, this quarter of an inch in a bar, let us say, 12 inches wide, represents only 3 cubic inches or one-thousandth per inch. It represents only 12 pounds per foot, or say, 150 pounds per bar; therefore if there is a variation of an ounce per foot from beginning to end, it would certainly not affect the rate of freezing. I am not talking now about theoretical conditions; I am talking about purely practical conditions, and particularly I am talking about the comparison between the process of ordinary ingot casting where you pour the metal and trust to luck, which is against you, and the process where you have a large amount of control of freezing, though not perfect control of freezing. We have not reached that stage yet and probably never will.

F. R. PALMER: In this new machine that you are contemplating, how thick will your ingots be?

LEON CAMMEN: We are going to build a machine which will cast ingots 12 inches by 4; the billets are primarily intended for skelp rolling and will be 13 feet 9 inches long.

THE DECOMPOSITION OF THE AUSTENITIC STRUCTURE IN STEELS—Part V*

X-Ray Studies on The Decomposition of Austenite

By Oscar E. Harder and Ralph L. Dowdell

Abstract

This part of the paper reports the application of the powder method of X-ray analysis to the study of changes in the structure of steels during heat treatment. The steels used in the investigation are the same as those described in Part I of this paper. A few tests have been made on powders filed from quenched specimens, but the method was discarded as unsatisfactory. The preparation of the powder in the annealed steels, followed by the desired heat treatments and X-ray analysis, gave satisfactory results. The steels have been examined in three conditions: 1, as quenched; 2, after submersion in liquid oxygen; 3, after various tempering treatments. The results are in general agreement with the results of the microscopic examination previously reported. The results show, however, that on submersion in liquid oxygen there is not the increase in the intensity of the alpha lines expected from the amount of martensite formed in larger specimens in the same treatment. The results indicate that certain transformations which produce the martensitic structure give alpha particles which are too small to be recorded in a crystallogram. Consideration is also given to the position of the carbon in the space lattice of the steels investigated. From a compilation of the evidence from the unit parameters and a comparison of these values with the values determined experimentally, the evidence indicates that the carbon is held within the space lattice and does not replace the iron atoms. The evidence is more conclusive in the case of austenitic than in the case of the martensitic steel.

*This and five other articles on The Decomposition of the Austenitic Structure in Steel are based on a manuscript submitted by Ralph Lewis Dowdell in partial fulfillment of the requirements of the Graduate School of the University of Minnesota for the degree of Doctor of Philosophy. O. E. Harder, in charge of research. These articles have appeared serially in Transactions since January, 1927. Seven installments constitute this series.

A paper presented before the eighth annual convention of the Society, Chicago, September 20 to 24, 1926. Of the authors, Dr. R. L. Dowdell is assistant professor of metallography and Dr. O. E. Harder is professor of metallography, University of Minnesota, Minneapolis.

AN X-Ray diffraction apparatus, type VWC, form B, devised by Hull[1] and made by the General Electric Co. of Schenectady, N. Y., was used in the X-ray examinations. Long exposures (50 hours) were required in the work because of the strong filtering action of the zirconium, but this filter was found necessary by Hull in order to simplify the patterns.

Preparation of Samples

The samples for X-ray analysis were prepared from specimens in the various conditions, as quenched and as annealed. All of the samples for the X-ray tests were prepared by filing. All of the filings made throughout this investigation were screened through 200 mesh silk bolting cloth. The filings that did not pass through the cloth were ground in an agate mortar until they did pass. A cotton partition was wedged into the center of the glass sample tube. The filings were then mixed with an equal volume of starch and packed into one half of the tube. The other half of the tube was packed with a mixture sodium chloride diluted with an equal volume of starch.

A sample of Yensen's electrolytic iron was filed from the bar as received and included to show the space lattice of high purity iron alpha. (Fig. 129, Film No. 30).

Filing Quenched Specimens. Steels No. 2 and 3 were filed in the quenched condition by filing slowly. It was thought that even careful filing would produce a considerable amount of alpha-iron from an austenitic specimen, but the absence of the alpha pattern in steel No. 2 shows that such is not the case with an austenite of high stability. As the amount of sample required was not more than 0.1 gram there was not much difficulty.

Filing Annealed Specimens Followed by Heat Treatment. Samples of all the steels except No. 2 were filed from annealed specimens, passed through 200 mesh cloth and then put into small silica tubes of about 1/32 inch bore by about 2½ inches in length, which had one end sealed. These tubes were then evacuated and sealed under vacuum. They were then heated to the temperatures shown in Table XI and after fifteen minutes were quenched in cold water at about 50 degrees Fahr. (10 degrees Cent.) Quenching time probably did not exceed 5 seconds. On removal from the water

[1]Physical Review 1917, Vol. 10, No. 6, pp. 661-696.

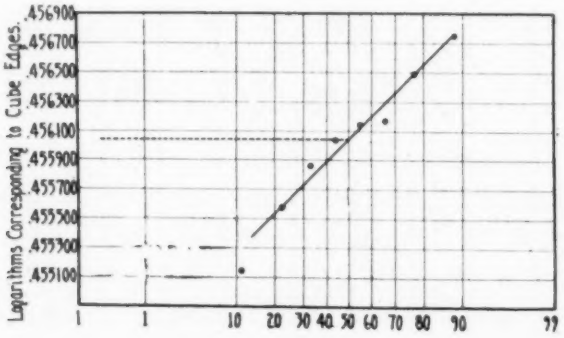
Table XI

Summary of Results of X-Ray Analyses

Steel Number and Name	Treatment No. 1 Quenched from 2102 Deg. Fahr. Angstrom Units		Treatment No. 2 Quenched from 1832 Deg. Fahr. Angstrom Units		Treatment No. 3 Quenched from 1832 Deg. Fahr. Angstrom Units		Treatment No. 4 Quenched from 1832 Deg. Fahr. Angstrom Units		Treatment No. 5 Quenched from 1832 Deg. Fahr. Angstrom Units		Remarks
	α	γ	α	γ	α	γ	α	γ	α	γ	
Yensen's Vac. Elec. Iron..	2.858	....	....	....	....	....	....	....	....	....	....
Steel No. 1 Co-Cr.....	....	....	....	3.6065	....	3.5944	2.860	3.6061	a only 2.8691	....	....
Steel No. 2 "Hadfield" Mn	....	γ only 3.6068	....	3.6083	....	3.6111	....	....	....	....	γ only
Steel No. 3 "Bain's" C-Cr	2.8643 2.856	3.5948	....	3.5934	....	3.5932	2.8556	3.5913	a only 2.8589	....	....
Steel No. 4 High Speed...	....	....	....	? 3.5780	2.8513	3.5757	....	....	2.8691	....	....
Steel No. 5 High C-Ni....	....	....	1652 Deg. Fahr. γ only 3.6062		1652 Deg. Fahr.	3.5954	1652 Deg. Fahr.	3.5911	1652 Deg. Fahr. γ only 3.5881		γ only
Steel No. 7 Cr Magnet...	....	....	2.8562	3.5995	2.8553	3.5904	....	....	a only 2.8637	....	....
Steel No. 8 C-W.....	....	....	....	3.5985	....	3.5904	2.8557	3.5862	....	....	....
Steel No. 10 High C.....	....	....	1652 Deg. Fahr.	3.6005	1652 Deg. Fahr.	3.5997	1652 Deg. Fahr. 2.8618	3.6116	1652 Deg. Fahr. 2.8598	....	....
Average	2.8594	3.6008	2.8562	3.6037	2.8533	3.5938	2.8583	3.5973	2.8641	3.5881	....

NOTE: Treatments. No. 1 = Filed after heat treatment.
No. 2 = Quenched filings, 200 mesh, heated in vacuo and quenched.
No. 3 = Same as No. 2 after 70-hour submersion in liquid oxygen.
No. 4 = Same as No. 2 after tempering 8 weeks at 212 degrees Fahr. (100 degrees Cent.).
No. 5 = Treatment No. 4 plus tempering 5 days at 374 degrees Fahr. (190 degrees Cent.).

the tubes were wiped dry and the ends broken off. Three samples for X-ray analysis were made from each of these steels. One set of samples was X-rayed as quenched. The second set was kept submerged in liquid oxygen for about 70 hours. The third set



Graph 3—Corrections for X-ray Lines as Tabulated in Column 3 of Table XII.

was sealed in pyrex glass and tempered for 8 weeks at 212 degrees Fahr. (100 degrees Cent.) after which most of them were X-rayed. They were then resealed in pyrex and tempered for five days at 374 degrees Fahr. (190 degrees Cent.) after which some were again X-rayed.

Method of Calculation and Interpretation of Films

The method of calculating the lattice parameters may be best shown by taking film No. 30 as an example. The film was slipped into a special frame supplied with the apparatus. The zero on the scale was made to coincide with the zero line produced on the film, or better by slipping the film in the frame until the second sodium chloride band read 1.990 Å (Angstrom Unit) on the scale. The sodium chloride lines were then read and tabulated in the first column on the data sheet for film No. 30, Table XII. The results obtained on each of the steels tested were arranged in this manner but are not reproduced here. The theoretical values of the sodium chloride lines as worked out by Hull were tabulated in the second column. The corrections for the lines were then tabulated in the third column and the curve plotted in Graph 3. The steel sample lines were then read and tabulated in the fourth column. The values in this column were then corrected and tabulated in the fifth column under the heading "corrected readings." The logarithms of these readings were tabulated in the column labeled "Log.

Table XII

X-Ray Data on Yensen's Electrolytic Iron

Filings from specimens as received. NaCl					Film No. 30; Exposure 40 hours. Electrolytic Iron			
Reading Film —	Theoretical +	Correction	Reading Film	Corrected Reading	Log. cor. Reading	Log 1/Ratio	Log. Reading + Log 1/Ratio	Indices of Form
2.825	2.814	−.011						
1.990	1.990	.000	2.020	α 2.020	.3053514	.15051	.4558614	110
1.625	1.625	.000						
1.406	1.407	+.001	1.425	α 1.426	.1541195	.30103	.4551495	100
1.258	1.259	+.001						
1.149	1.149	.000	1.167	α 1.167	.0670709	.38907	.4561409	211
.993	.995	+.002	1.010	α 1.012	.0051805	.45154	.4567205	110
.938	.938	.000						
.888	.890	+.002	.902	α .904	.9561684	.50000	.4561684	310
.848	.848	.000						
.810	.812	+.002	.823	α .825	.9164539	.53959	.4550439	111
.752	.752	.000	.763	α .763	.8825245	.57306	.4555845	321
			.674	α .674	.8286599	.62763	.4564899	110

Log α = .456040
α = 2.858 angstrom unit.

corrected read." The values in the column labeled "Log 1/Ratio" are taken from Table XII.[2] On this table 1/Ratio is the square root of the sums of the squares of the indices of form (Miller indices). These Miller indices are the reciprocals of the intercepts in the cartesian system of coördinates which represent the planes For instance the first line on the film is the first order representation of the 1 1 0 planes and the intercepts on the x, y, and z axes are x = 1, y = 1 and z = infinity. These planes are then parallel to the z axis and cut the x and y axes at unity. For the simple cubic lattice of unity the distance between planes parallel to the 1 1 0 is 1/Ratio which is the square root of the sum of the squares $(1)^2 + (1)^2 + (0)^2$ which is equal to the square root of 2. The $\log_{10}$ 1/Ratio is then 0.15051.

The values in the column labeled "Log of the reading plus the Log of 1/Ratio" are simply found by adding these two logarithms. The number corresponding to this log represents the unit parameter or the cube edge of the ferrite (alpha iron). This value is arrived at as follows: The angle of the incident ray is taken into account in the design of the apparatus by using Bragg's law so that the interplanar distance (d) is measured directly for this 1 1 0 line and is read from the film as 2.020 Å. The Braggs[3] and others have shown that the edge of the unit cube as calculated from the 1 1 0 plane is as given in the formula.

$$d_{110} = \frac{a}{\sqrt{2}} \qquad a = \text{edge of the cube}$$

$\sqrt{2}$ = distance between successive planes (110)

$$a = 2.020 \times \sqrt{2}$$

$$\log a = \log 2.020 + \log \sqrt{2}$$

$$\log a = 0.30535 + 0.15051 = .45586$$

The log values for all the planes shown on the film were worked out in this manner and tabulated. These values in increasing order are then plotted on probability paper as the ordinates while the abscissae units for each point are found by dividing 100 by the (number of lines + 1) and plotting as shown on Graph 3. It is considered more accurate to reject the values below 30 and above 70 and draw a straight line to represent the remainder of the points. Where this line crosses the 50-50 line, the logarithm is read on the ordinate which represents the side of the elementary cube for the

[2]General Electric Review, Vol. 29, page 122, 1926, by Dr. Davey.

[3]X-Rays and Crystal Structure, 4th Edition, 1924. Harcourt, Brace & Co., New York, publishers.

average of all of the coöperating planes in the cubic lattice. The lattice parameters as measured by this method are considered by Davey to be correct to ± 0.003 Å.

Experimental Data from X-Ray Analyses

In the following pages the experimental results obtained by X-ray analyses of the various steels after different treatments will be given. Prints from only a few of the films are included. A summary of results will be found in Table XI.

a. Steel No. 1. Steel No. 1 after treatment 2 (filings after quenching in water) showed both the alpha and the gamma lines but the gamma lines were stronger and in greater number. This steel after treatment 3 (cooled 70 hours in liquid oxygen) showed a decrease in the number of gamma lines but no increase in the number of alpha lines. This may be due to the breakdown of austenite into alpha particles which remained too small to give the alpha pattern. After treatment 4 it showed an equal number of alpha and gamma lines but the alpha lines were stronger. This increase in the alpha pattern may be due to the increase in the amount of the alpha phase and the size of the alpha particles at 212 degrees Fahr. (100 degrees Cent.). The film, after treatment 5, quenching from 1832 degrees Fahr. (1000 degrees Cent.) and tempering up to 374 degrees Fahr. (190 degrees Cent.), showed a strong alpha pattern and the complete absence of the gamma pattern. The complete breakdown of the austenite at 374 degrees Fahr. (190 degrees Cent.) may be attributed to the fineness of the particles (200 mesh) because it had been previously observed that the austenitic structure in ⅜ inch round pieces was not completely decomposed up to 932 to 1112 degrees Fahr. (500 to 600 degrees Cent.).

b. Steel No. 2. On examination of the values given in Table XI it will be noticed that steel No. 2 gave a complete gamma pattern on a sample filed from an austenitic specimen. The filings were, however, magnetic but there does not seem to have been enough alpha present to give any alpha lines. Fig. 129, Film 53, shows a complete pattern of gamma iron only from this steel which had been quenched in the form of 200-mesh filings. This film has been included in Fig. 129 as an aid in identifying the gamma patterns of the various films of steel No. 3 and also to aid in following the

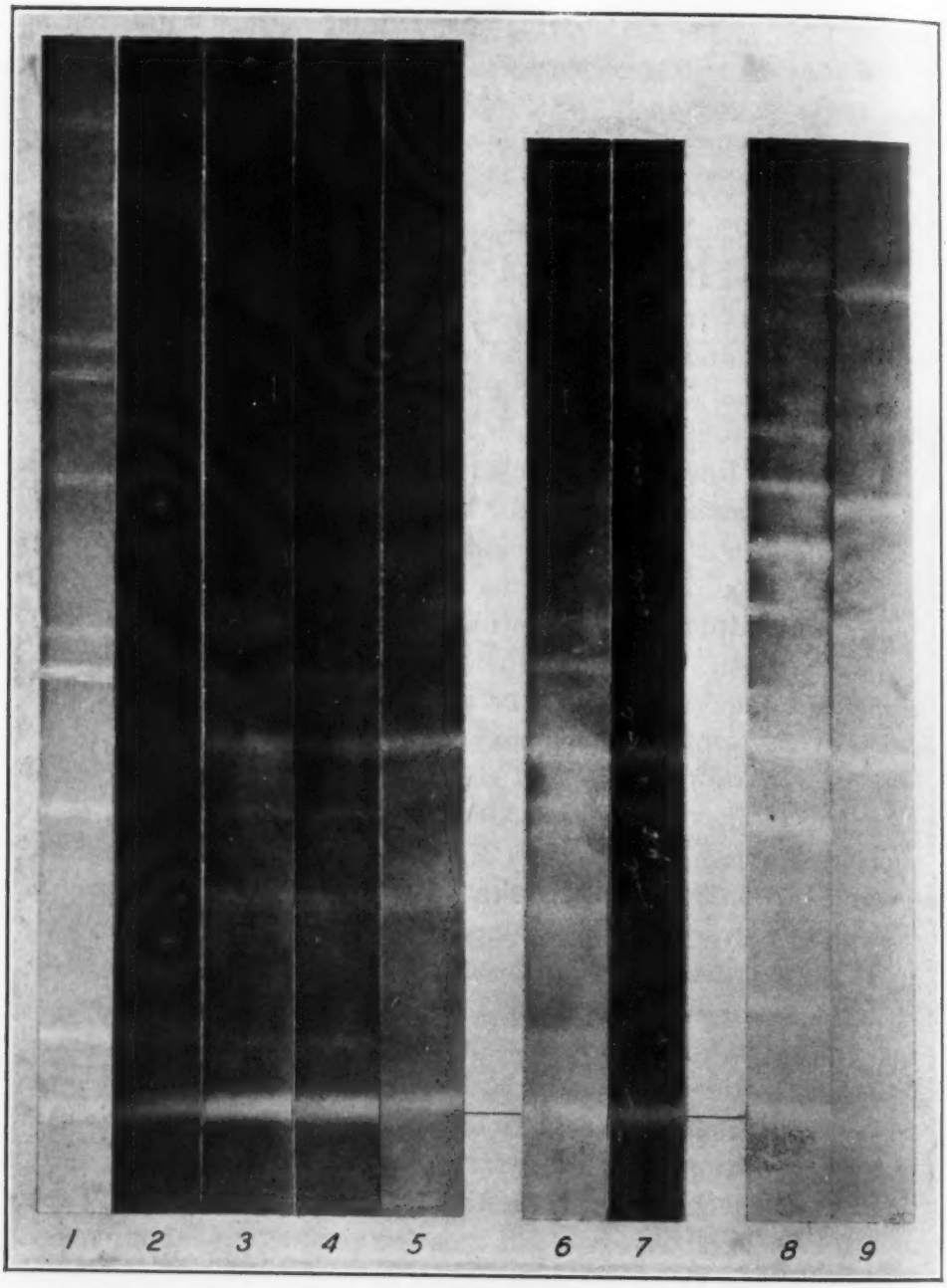


Fig. 129 is a Reproduction of the Crystallograms Obtained from the Steels which were given Various Treatments, also of Sodium Chloride and of Yensen's Electrolytic Iron.

Crystallogram 1 is film 53 of steel 2 treatment 2, it is shown to be all γ.

Crystallogram 2 is film 45 of steel 3 treatment 2, it shows that the $\gamma > \alpha$.

Crystallogram 3 is film 56 of steel 3 treatment 3, it shows that $\gamma > \alpha$.

Crystallogram 4 is film 61 of steel 3 treatment 4, it shows that $\gamma = \alpha$ or $\gamma < \alpha$.

Crystallogram 5 is film 85 of steel 3 treatment 5, this shows α only.

Crystallogram 6 is film 74 of steel 3 treatment 1, it is as quenched and shows $\alpha = \gamma$.

Crystallogram 7 is film 31 of steel 3 treatment 1 after submersion in liquid oxygen, this is α only.

Crystallogram 8 is film 30 of sodium chloride.

Crystallogram 9 is film 30 of Yensen's electrolytic iron, treatment 1.

decomposition after the various treatments. After treatment 3, steel No. 2 showed one weak (1 1 0) alpha line. Tempering experiments were not made on the quenched filings of this steel.

c. Steel No. 3. Fig. 129 also showed the effect of the various treatments 1 to 5 on steel No. 3. The pattern of pure ferrite is included for reference. Film No. 74 and the data in Table XI show that the alpha and gamma patterns are of about equal intensities for filings from a quenched sample of steel No. 3. Film No. 31 shows only alpha in the sample filed from a quenched specimen which had been submerged in liquid oxygen for about 100 hours. Under the microscope the piece appeared to have about 50 per cent austenite. Film No. 45 after treatment No. 2, shows mostly a gamma pattern. Film No. 56 after treatment No. 3 (cooling in liquid oxygen) shows gamma in greater intensity than alpha and shows no detectable change from Film No. 45. Film No. 61 of treatment No. 4 shows that the alpha pattern is coming into slight excess due to the tempering action or at least its intensity is about equal to the gamma pattern. It should be noted that films No. 45, 56, and 61 of Fig. No. 129 have their first line composed of both the alpha and the gamma patterns uniting to form a rather wide line. Film No. 56 shows this line very much shaded on the left side indicating a greater intensity of gamma, while this first line in film No. 61 shows just the reverse or shading on the right side, which shows that the 1 1 0 plane of ferrite seems to predominate. Film No. 85, after treatment No. 5, shows that only the alpha pattern exists after tempering at 374 degrees Fahr. (190 degrees Cent.).

d. Steel No. 4. Steel No. 4, treatment 2, showed mostly the carbide lines. The identity of these lines was brought out by comparison with data obtained on graphite and cementite. There was an indication of weak lines of both alpha and gamma; however, these lines were not in the orders usually obtained, the gamma lines being of the second and third orders. There is a possibility of the carbide lines interfering with the others. Cooling samples of this steel in liquid oxygen for 70 hours brought out more gamma and alpha lines. On tempering this steel at 374 degrees Fahr. (190 degrees Cent.), the intensity of the alpha lines is considerably increased while all of the gamma lines except one disappeared and that one was quite weak.

e. Steel No. 5. This steel showed only gamma lines after all

of the treatments. This high nickel steel (22 per cent) appears to form such a stable austenite that even in the finely divided particles it is not decomposed by cooling in liquid oxygen or by heating to 374 degrees Fahr. (190 degrees Cent.) for a period of 5 days. This steel was also found to be very stable when large pieces were tempered.

f. Steel No. 7. This steel after treatment 2, showed almost entirely the gamma pattern. Some alpha lines were noted but they were weak. After treatment 3, cooling in liquid oxygen, the crystallogram showed that gamma still predominated and remained unchanged. However, when the sample was tempered 5 days at 374 degrees Fahr. (190 degrees Cent.) the gamma pattern completely disappeared. This indicates a somewhat lower temperature for the decomposition of austenite in the small particles than would be found in the large sized sample.

g. Steel No. 8. Steel No. 8, after treatment 2, showed gamma, alpha and carbide lines. There were more gamma lines and they were stronger than any of the others. Cooling a sample 70 hours in liquid oxygen, treatment 3, neither increased the intensity nor the number of the alpha lines. Tempering the samples 8 weeks at 212 degrees Fahr. (100 degrees Cent.), treatment 4, increased both the intensity and the number of alpha lines so that the alpha is stronger than the gamma pattern. Tempering tests on large sized specimens were not made.

h. Steel No. 10. The X-ray analysis of the quenched filings showed principally the gamma pattern. Alpha and carbide lines were present but the alpha lines were weak. The high carbon content of this steel and the comparatively low quenching temperature resulted in a considerable amount of undissolved carbide. Cooling this sample 70 hours in liquid oxygen showed no increase in the number or the intensity of alpha lines and the pattern remained essentially gamma. Tempering the sample 8 weeks at 212 degrees Fahr. (100 degrees Cent.), treatment 4, increased both the number and the intensity of the alpha lines so that the pattern is predominately an alpha pattern. Tempering at 374 degrees Fahr. (190 degrees Cent.) for 5 days, treatment 5, completely decomposed the austenite so that the gamma lines were entirely absent. It had previously been observed that large pieces of this steel showed a beginning of the decomposition in one day at 374 degrees Fahr.

(190 degrees Cent.) and a complete decomposition of the austenite after 4 days at 374 degrees Fahr. (190 degrees Cent.).

4. Results of X-Ray Analyses

The more important results of this investigation may be grouped under the following headings:

a. The austenitic structure is partly destroyed by filing the sample for X-ray analysis. A sample of steel No. 3 which, from microscopic examination was found to be wholly austenitic, showed the alpha and gamma patterns in equal intensity when the sample was prepared by filing. A specimen of steel No. 3 which from microscopic examination contained about equal amounts of austenite and martensite showed almost entirely the alpha pattern when the X-ray sample was prepared by filing.

b. The preparation of the steel samples to pass a 200-mesh bolting cloth followed by heat treating in vacuo has been found to be a satisfactory method of preparing steel samples for X-ray analysis. By sealing the samples in silica tubes it has been found possible to heat to the desired temperature and to quench with considerable rapidity in water.

c. The presence of undissolved carbides has been found to be objectionable in samples for X-ray analysis. The carbides give a large number of lines which may interfere with the alpha and gamma lines. It would appear that if possible the samples should be heated sufficiently high and for a long enough time to put all of the carbide into solution.

d. Cooling 70 hours in liquid oxygen has not increased the intensity of the alpha patterns of the steels tested. Even in the cases of the steels which showed definite martensitic formation on microscopic examination of the large sized pieces, when cooled in liquid oxygen there was no increase in the intensity of the alpha pattern. The microscopic evidence indicates a definite recrystallization from gamma to alpha and the following explanation is offered for the absence of any increase in the intensity of the alpha pattern. At the low temperature of liquid oxygen the crystal nuclei of alpha which are formed do not grow to sufficient size to give an X-ray diffraction pattern. This suggests the extremely small size of the alpha particle in the martensite formed at low temperatures.

e. X-ray analyses of the samples which had been tempered 8 weeks at 212 degrees Fahr. (100 degrees Cent.) showed a pronounced increase in the number of alpha lines in all samples in which the alpha pattern had been present. This increase in the intensity of the alpha pattern during the tempering treatment at 100 degrees Cent. may be attributed to two important factors; i. e. continued recrystallization and growth of the ferrite particles.

f. In all of the steels tested in the form of quenched filings, except Nos. 2 and 5, the gamma pattern completely disappeared after tempering at 374 degrees Fahr. (190 degrees Cent.). This is considered to mean the complete breakdown of the austenite and the growth of the ferrite particles into such size that they increase the intensity of the ferrite pattern. Steel No. 5 was an extremely stable austenite and showed only the gamma lines after the 374 degrees Fahr. (190 degrees Cent.) tempering treatment.

g. The relatively greater intensity of the gamma pattern as compared with that of the alpha pattern in the quenched filings of the steels which showed larger amounts of martensite in microscopic specimens, may be attributed to the finely divided condition of the ferrite particles. This suggests the fineness of the ferrite particles in martensite produced during quenching.

h. The apparent contradiction between the results of X-ray analyses and the previous conclusions from microscopic examination regarding the effect of stress may be explained by the presence of alpha particles in the martensite in such a finely divided condition that they do not produce the alpha pattern on X-ray analysis. It is also possible that the effect of stress is largely eliminated when the 200-mesh particles are quenched.

i. X-ray evidence at room temperature of 200-mesh austenitic particles of steel shows that the gamma lattice is contracted after submersion in liquid oxygen. The average value of eight steels before submersion shows gamma to be 3.6037 Å units while after about six weeks submersion the same steels averaged 3.594 Å. This difference is far too large to be due to any experimental error.

Westgren's results on a nickel steel containing 25 per cent nickel with 0.24 per cent carbon showed a value of 3.58 Å before submersion in liquid oxygen while after submersion this steel showed only 3.54 Å.

These austenitic powders were tempered at 212 degrees Fahr.

(100 degrees Cent.) and X-rayed at room temperature about two months afterwards. The average alpha lattice parameters were found to be 2.8581 Å. After tempering at 374 degrees Fahr. (190 degrees Cent.) these steel powders showed an average value of 2.8641 Å.

These experiments indicate that the temperature effects on the lattice parameter cause somewhat of a permanent set on the parameters, or that there is a hysteresis effect in the change of the parameter with change of temperature. This relation is more definitely shown in the case of the gamma pattern.

j. X-ray evidence shows that the calculated lattice parameter of pure electrolytic iron gives 2.858 Å units. Davey[4] found a value of 2.861±.003 Å for an iron reduced with hydrogen and 2.855 Å for vacuum fused electrolytic iron. His higher value for the iron reduced by hydrogen may have been due to the spreading of the lattice by dissolved hydrogen similar to the cases of Palladium and Platinum reported by Yamada[5], McKeenhan[6], and Osawa.[7] This value also checks that of Hull[8] (2.86) and that of Wever[9] (2.863) fairly well.

k. X-ray results show that the lattice parameter of electrolytic iron is practically the same as that of the alpha formed when high carbon and high alloy austenitic structures decompose either on quenching or on tempering. However, the lines of alpha produced in the decomposition of austenite are not as intense and are frequently wider than those of electrolytic iron which may indicate, as Westgren[10] has stated, that this ferrite is finer grained. However, the width of the sodium chloride lines varied considerably in the crystallograms investigated, even when made from the same sample, and it might be expected that the ferrite patterns would vary.

l. The values of the gamma parameter of steel No. 2 containing 11.88 per cent manganese with 1.37 per cent carbon gave

[4] TRANSACTIONS, American Society for Steel Treating, 1924, Vol. VI, pp. 375-392.

[5] Phil. Mag. 14, January, 1923.

[6] Phys. Rev. 21, March, 1923.

[7] Science Reports, Tohoku Imp. Univ. XIV, 1925.

[8] Phys. Rev. 1917, Vol. IX, No. 6, p. 681.

[9] *Journal*, Iron Steel Institute 1922, Vol. CV, pp. 241-262.

[10] *Journal*, Iron Steel Institute 1922, Vol. CV, pp. 241-62.

3.608 Å. This is very close to Westgren's values on a manganese steel containing 12.1 per cent manganese with 1.34 per cent carbon which are 3.61 to 3.624 Å.

The gamma parameter of steel No. 5 containing 22.57 per cent nickel and 0.99 per cent carbon was found to be 3.606 Å. Westgren reported a value of 3.64 Å for a steel containing 24.3 per cent nickel, 6.05 per cent manganese with 1.18 per cent carbon.

Westgren[11] did not find the gamma pattern on oil quenching a 2 millimeter section of high speed steel from 2330 degrees Fahr. (1275 degrees Cent.) probably due to a too drastic cooling which resulted in the formation of martensite. He reported 2.86 Å for the alpha pattern of this steel. The gamma parameter obtained from quenched powder of high speed steel No. 4 was 3.578 Å. (This value was calculated from only two planes, 2 1 1 and 1 1 0). The alpha lattice found for this steel was 2.851 Å.

The gamma parameter of steel No. 10 containing 2.66 per cent carbon was found to be only 3.60 Å. This low value may have been caused by a low carbon austenite due to insufficient time at the quenching heat to put all of the carbide into solution. On a similar steel of 1.98 per cent carbon Westgren and Phragmen[12] obtained a value of 3.64 Å.

m. Owing to the size and shape of the cementite unit cell which has been found[13] to be an orthorhombic parallelepiped consisting of $4Fe_3C$, it is very unlikely that it is dissolved as a unit in either austenite or martensite by a simple replacement of the iron atoms. Density determinations calculated from X-ray data indicate that the carbon atoms cannot all be situated so as to replace iron atoms in the gamma lattice. Many calculated density determinations from X-ray results have been reported to check quite closely with the actual specific gravity determinations for most of the pure metals.[14]

It should then be possible to determine something as to the position of the carbon which is in solution in the gamma iron.

Steel No. 2 ("Hadfield's manganese steel") and steel No. 3 ("Bain's high carbon-chromium steel") showed nearly an all

[11] *Journal*, Iron Steel Institute 1921, Vol. CIII, No. 1, pp. 303-325.

[12] *Journal*, Iron Steel Institute 1922, Vol. CV, No. 1, pp. 241-262.

[13] *Journal*, Iron Steel Institute 1924, Vol. CIV, No. 1, pp. 159-174.

[14] TRANSACTIONS, American Society for Steel Treating 1924, Vol. VI, No. 3, pp. 375-392.

austenitic structure both by the microscope and by X-ray diffraction, so they were chosen for the following calculations:

Steel No. 2

Composition	Weight per cent	Atomic per cent	Atomic weight
Iron	86.09	81.31	55.84
Manganese	11.88	11.40	54.93
Silicon	0.66	1.21	28.1
Carbon	1.37	6.02	12.0

If the carbon, manganese and silicon atoms are replacing the iron atoms in the lattice, the calculated density will be:

$$\frac{4(52.72)\times(1.650)\times(10^{24})}{(3.608)^3\times(10^{-24})} = 7.41$$

Where 4 = Number of whole atoms in the unit face-centered cubic lattice 52.72 = Molecular weight of the sample (1.650) (10^{-24}) = Mass in grams of an atom of unit atomic weight.

The above calculated density value is far too low as compared with the actual density of the steel (7.812). However, if the carbon atoms are postulated to occupy positions inside of the gamma iron lattice and silicon and manganese are calculated to replace the iron atoms, we have:

$$\frac{4(56.103)\times(1.650)\times(10^{-24})}{(3.608)^3\times(10^{-24})} = 7.88$$

This value is considerably closer to the actual value determined by weighing (7.812).

Westgren's[15] calculation on a similar steel checked absolutely his experimental density determination (7.83).

If steel No. 3 be taken for these calculations, we will have:

Composition	Weight per cent	Atomic per cent
Iron	86.36	78.93
Chromium	10.56	10.37
Carbon	2.22	9.44
Silicon	0.50	0.908
Manganese	0.36	0.314

$$\frac{4(51.04)\times(1.650)\times(10^{-24})}{(3.593)^3\times(10^{-24})} = 7.26$$

[15] *Journal*, Iron Steel Institute, 1924, Vol. CIV, No. 1, pp. 159-174.

for the calculated density when manganese, silicon, chromium and carbon replace the iron in the gamma lattice. This value is also too small as compared with the experimental (7.981).

However, if the carbon atoms are postulated to occupy positions inside of the gamma lattice and only silicon, manganese and chromium are calculated to replace the iron atoms, we will have:

$$\frac{4(46.28)\times(1.650)\times(10^{-24})}{(3.593)^3\times(10^{-24})} = 8.008$$

which checks the value 7.981 very closely. These calculated values are higher in both steels which may indicate voids in the large pieces. In fact, steel No. 2 showed voids that could be detected with the microscope.

These calculations seem to show that the carbon is included inside the space lattice of the gamma iron and does not replace the iron atoms in the lattice. It may be postulated that in this position the carbon, owing to its affinity for iron, has a bonding with adjacent iron atoms.

THE AUTOMATIC ELECTRIC FURNACE — ITS USES AND POSSIBILITIES

By Harold F. Wood

Abstract

The automatic heat treatment of the modern automotive crank shaft involves some interesting engineering problems when the great variety of designs of crankshafts is considered. The fact that these designs are constantly being changed as motor engineering progresses, makes it impossible to arrive at any standard to be used in furnace design that would remain a standard while the furnace was being designed and installed. With this condition existing, it was necessary to deviate somewhat from the beaten path, and design equipment which would heat treat any forging without the knowledge of its details of design in mind, other than that it must not be over four feet in length and nine inches in greatest width. It was with this broad idea in mind that the equipment described was designed and installed.

Mechanical Design

THE equipment consists of two rotary-hearth electric furnaces, one to be used for hardening and the other for tempering (drawing), with automatic charging and discharging devices on each furnace, automatic quenching mechanism, and transfer conveyors. The two furnaces are exact duplicates mechanically, (Fig. 1). The diameter of the outer shell is 32 feet, and the inner shell 15 feet, the mean diameter of the hearth being 23 feet, 6 inches. Both the outer and inner shells are made of heavy reinforced steel plate, with riveted joints, and are supported on reinforced concrete foundations with a suitable pit underneath the hearth for easy access for inspection and lubrication.

The hearth is all structural steel construction, with railroad rails running on drop-forged and heat treated rollers, roller bearings being used throughout to reduce friction to a minimum. The thrust on the hearth is taken by adjustable horizontal rollers traveling against the side of the inner rail head. The hearth is driven by a 3-horsepower motor through proper speed reduction

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and crank arm to a simple pawl and ratchet, the ratchet being mounted on the underneath side of the hearth on the mean diameter of same. The pawl is attached to a crank arm and counterweighted so as to always remain engaged on the ratchet during all points of crank arm travel.

The furnace lining consists of 9 inches of firebrick or specially shaped tile, backed up with 12.5 inches of insulation. Adequate sand seals are provided on both inner and outer hearth circles to prevent leakage of cold air into the furnace.

Located radially on the top of the hearth are high grade, heat-resisting alloy castings, the legs of which are seated in small recesses in the hearth tile, which are indexed properly with the ratchet teeth. Heat-resisting alloy anchor castings, assembled from the underneath side of the hearth, project through the bottom of the hearth, and not only hold the hearth tile in proper index position relative to the ratchet teeth, but also engage a recess on the underneath side of the hearth castings, taking the thrust of charging and discharging of the product being treated. The index of the hearth is such that hearth castings are always in line with charging and discharging door castings, thereby making automatic charging and discharging possible.

On top of the furnace is mounted the motor driven charging and discharging mechanism. (See Figs. 2 and 3.) Through a proper speed reduction and gearing, a 3-horsepower motor drives two cams with crank pins mounted on the side of same. The crank pins are connected by means of I-beam connecting rods to heavy cross heads, sliding on bronze guides. These cross heads operate a specially designed link mechanism, three points of which are movable and one point stationary. The outer link arms are long. On the charger mechanism the long arm is attached directly to the charger head, and on the discharger mechanism it is attached through a short link to another cross head, which is connected by means of a round shaft to a heat-resisting alloy pusher head located in the inner wall of the furnace directly opposite the discharge door. Rolling on the contour of the cams are rollers connected through suitable bell cranks to the doors. The relative index of the cam contours and crank pins is such as to enable the doors to be open the minimum period possible of the operating cycle. A suitable shear key is located in the hub of the master driven gear to prevent any damage being done to the charging and

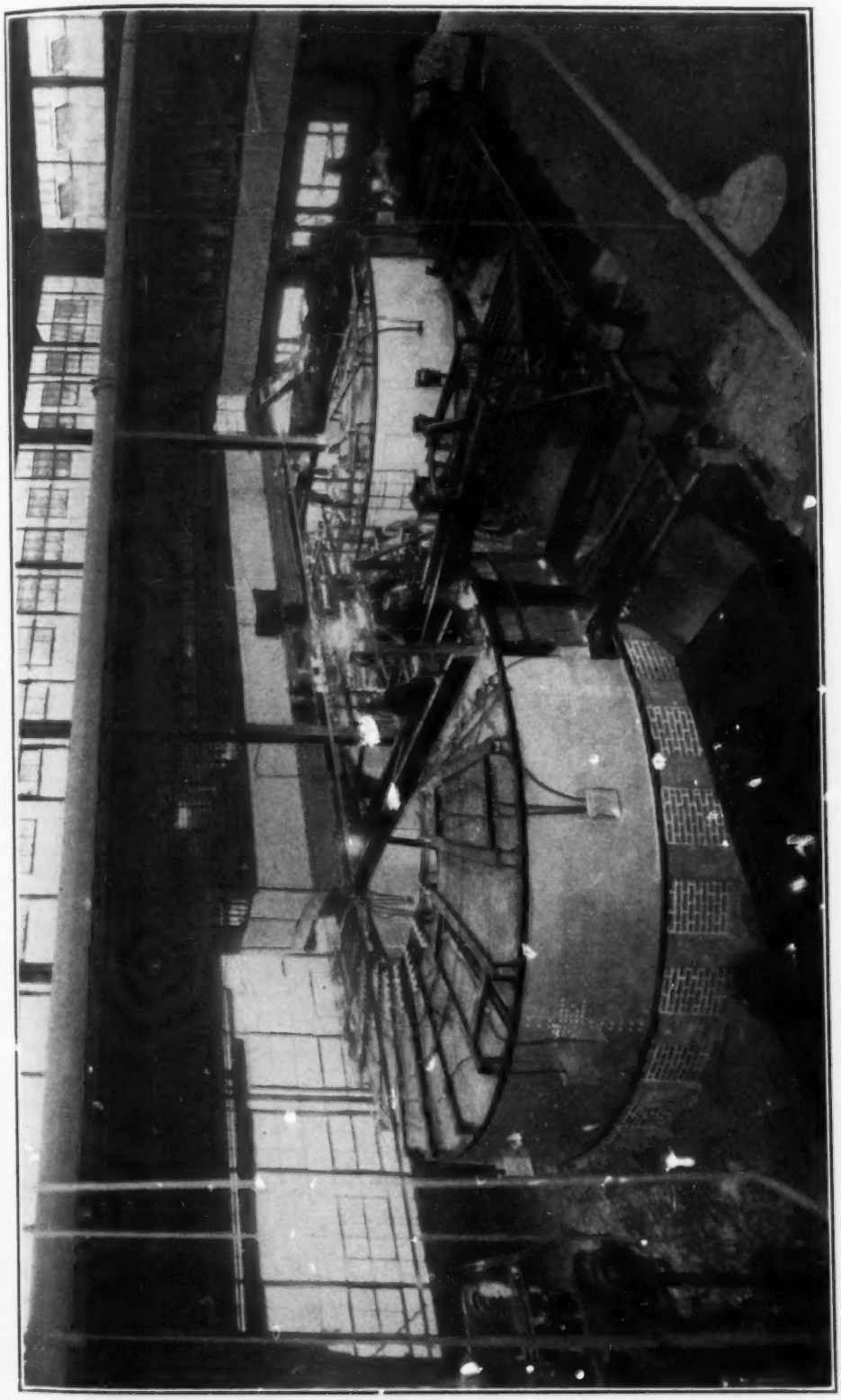


Fig. 1—General Arrangement of Furnaces Showing Quenching Tank and Conveyors.

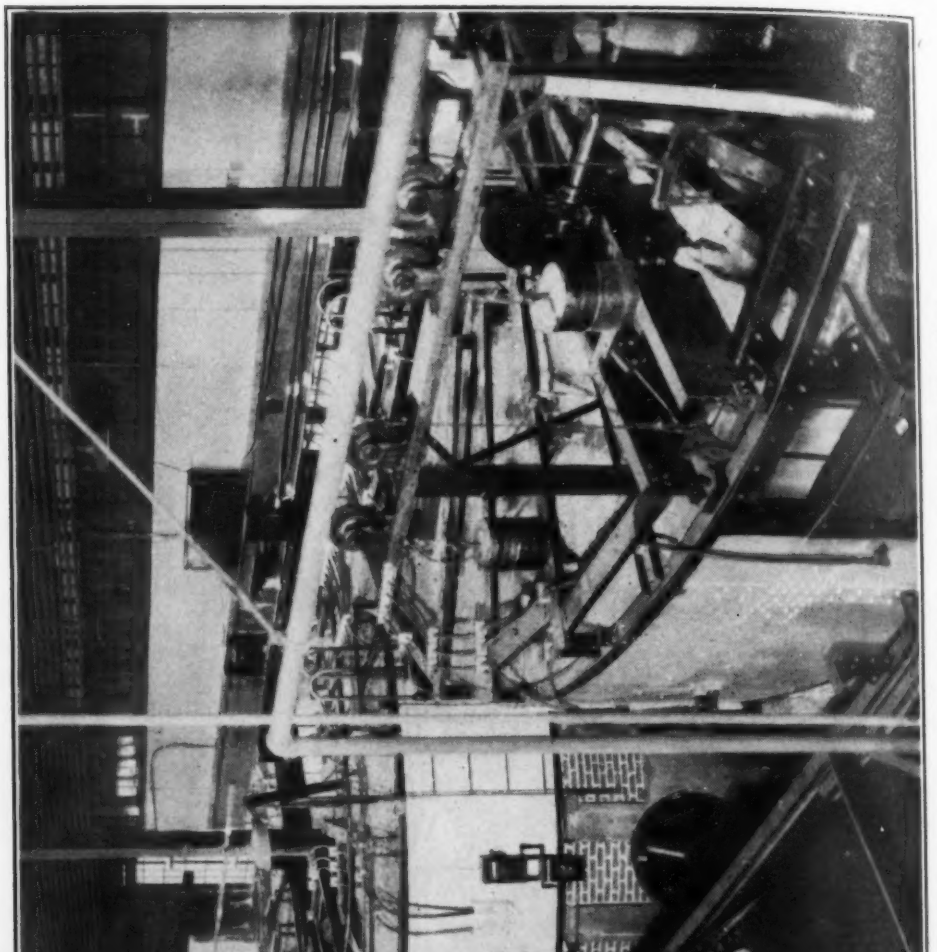


Fig. 2.—Arrangement of Conveyors Showing how Forgings are Delivered to Subsequent Operations.

discharging mechanism or to the furnace proper, should a forging be located improperly in the charging trough.

The forging is discharged from the hardening furnace upon the quenching mechanism. (Fig. 3.) The final 2 inches of stroke of the discharge pusher head trips the quenching mechanism and

Fig. 3—Charging and Discharging Mechanism in Operation Showing Forging being Deposited on Quenching Mechanism.

allows the forging to be immediately immersed in the quenching medium and be deposited upon a variable-speed conveyor for transfer to the tempering furnace. At the instant the forging falls from the conveyor down an incline to the tempering furnace charging trough, it engages a steel paddle which operates a switch to set the tempering furnace cycle in operation. The forging is discharged from the tempering furnace upon a mechanism which is an exact duplicate of the quenching mechanism, from which the forging slides on an inclined plane to a high speed conveyor, which carries it to the next operation after heat treatment.

In the control room is located an electric timer which determines hardening furnace time cycles. (Fig. 4 and 5.) This

timer is calibrated in 5-second intervals, which makes possible maximum flexibility in rates of production.

The charging and discharged mechanism, hearth drives and quenching tank conveyor are all interlocked electrically to guarantee proper sequence of operations. By means of this interlock-

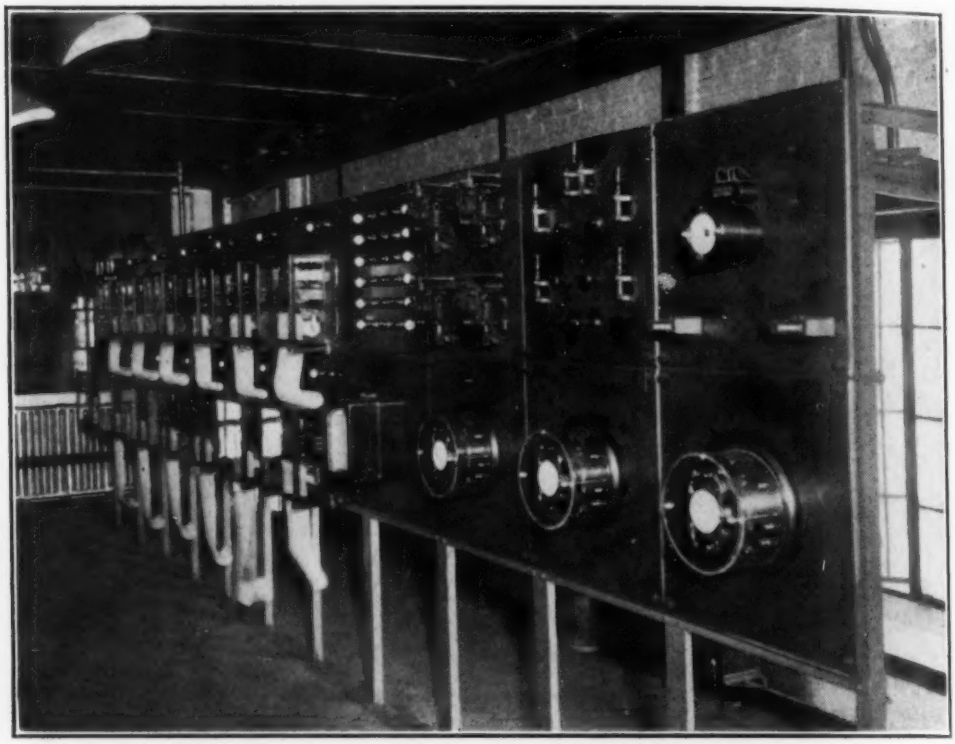


Fig. 4—Arrangement of Instruments in Control Room.

ing, it is impossible for the charging and discharging mechanism to function while the hearths are in motion, or out of proper index when stationary. It is also impossible for the hearth drive mechanism to function while the charging and discharging mechanisms are in motion or stationary at any point in the cycle except when the pusher heads are in their extreme outward position. The quenching conveyor is interlocked with the tempering furnace hearth drive and charging-discharging mechanisms, so as to prevent a second forging from being deposited in the tempering furnace charging trough before the preceding cycle has been completely finished. See Figs. 6 to 9 for detailed drawings of the furnace mechanism.

The furnace installation is located in the line of regular shop

operations. This makes it possible for the man performing the operation preceding heat treatment to load the hardening furnace trough with no extra effort. From this point on the forging is

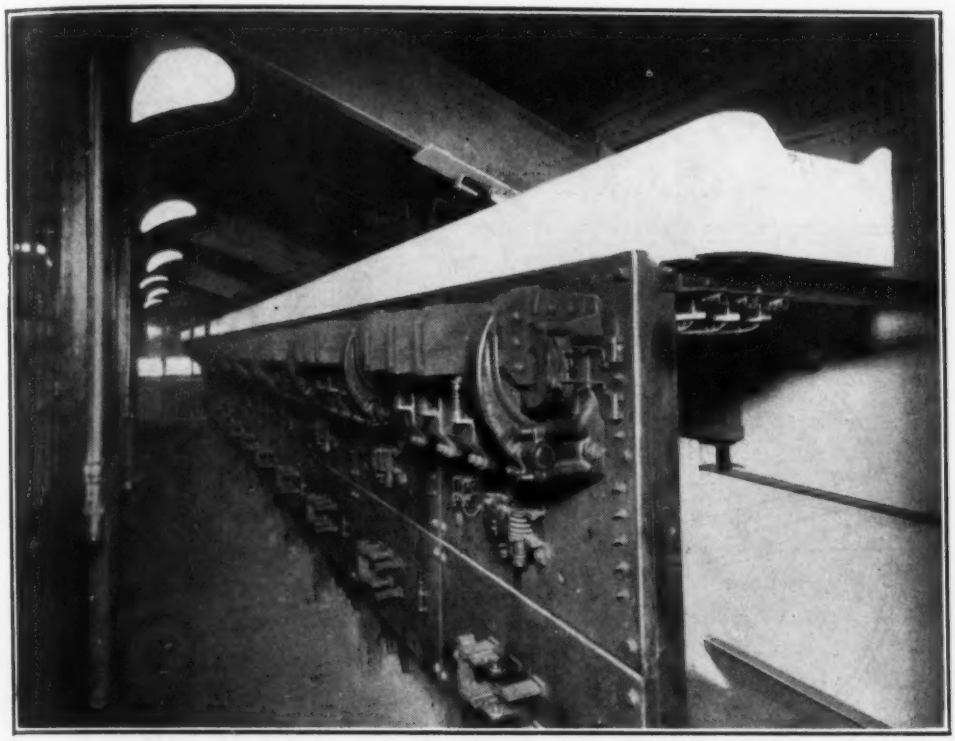


Fig. 5—Battery of Contractor Panels Operating Various Zones on Furnaces.

handled completely automatically, and when heat treated is delivered by conveyor to the man performing the regular operation immediately following the heat treatment.

Electrical Design

Each furnace is divided electrically into six zones. The kilowatt input in each zone operating on 235 volts is in accordance with Table I. (See Fig. 9.)

The maximum power input on the hardening furnace is 793 kilowatts and on the tempering furnace 720 kilowatts, making a total of 1513 kilowatts connected load. Each zone is controlled by means of a single-point recorder controller and safe-guarded by limit fuses. Although the total connected load is 1513 kilowatts, the maximum demand set up has never exceeded 1000 kilowatts,

Table I
Kilowatt Input

Zone No.	Hardening Furnace Kilowatts	Tempering Furnace Kilowatts
1.....	151	120
2.....	141	120
3.....	141	120
4.....	120	120
5.....	120	120
6.....	120	120

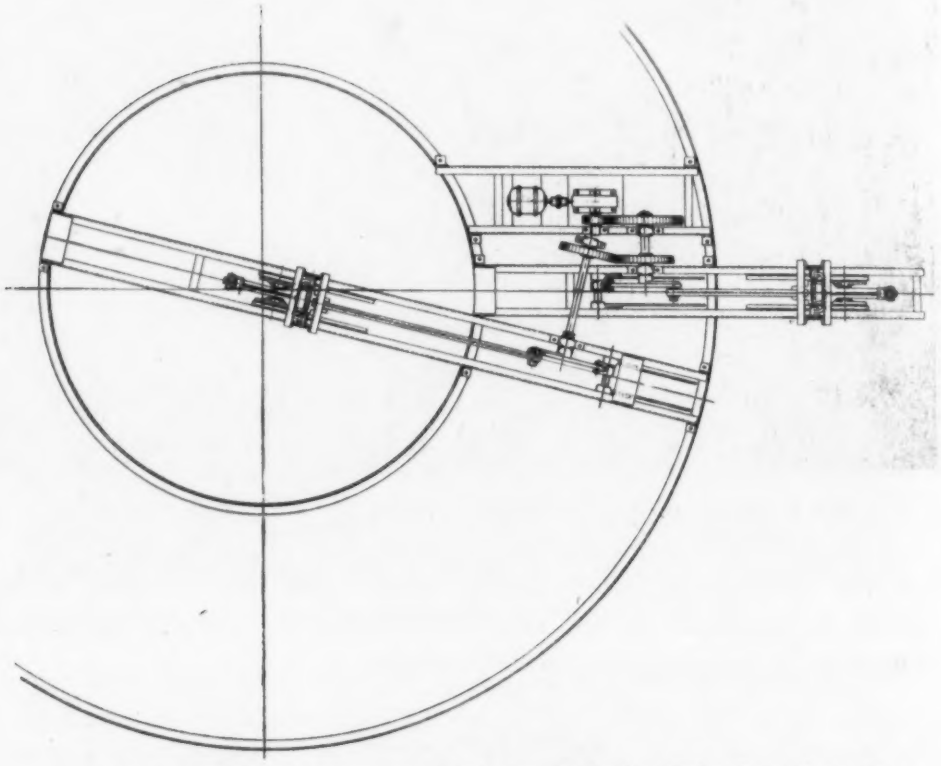


Fig. 6—Details of Charger and Discharger Mechanism Drive Located on Top of Furnaces.

due to the large number of zones that are controlled at temperature with the furnace running at capacity production.

Located in the control room are four meters: one measuring total power consumption on the primary side of the transformers; one measuring power consumption on the secondary side of the transformers of the hardening furnace; one measuring power consumption on the secondary side of the transformers of the tempering furnace; and a recording kilowatt hour meter showing maximum

demand at all times. (Fig. 4.) Connected in parallel with the charging and discharging mechanism control circuits are two magnetic counters which give very accurately production through

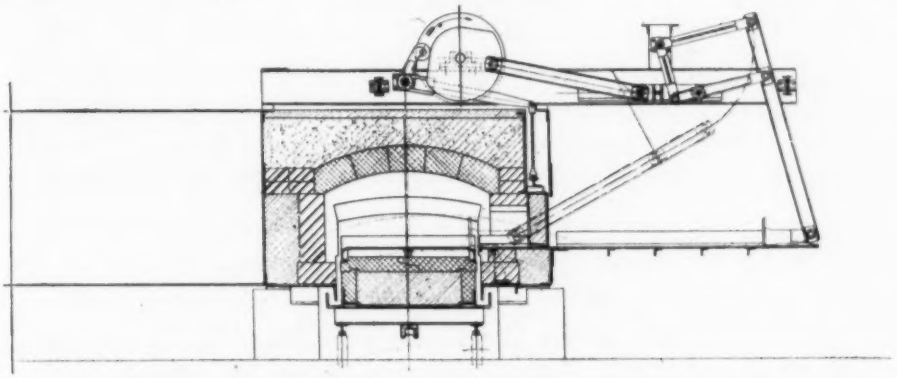


Fig. 7—Section Through Charging Door Showing Details of Charger Link and Cam Mechanism and Sectional Details of Furnace Proper.

the furnaces at all times. All meters are read at the beginning of each shift and complete performance of furnaces calculated. These records are invaluable if accurate furnace performance is to be secured.

Efficiency

Furnace efficiency records over a few hours or shifts are worthless in that they do not supply information that is indicative of what may be expected month after month. Table II shows both operating and net thermal efficiencies on installation for a three months' period.

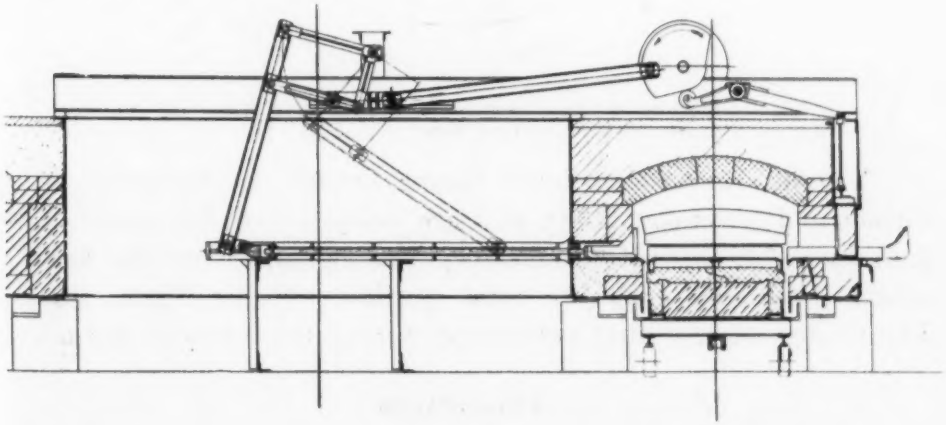


Fig. 8—Section Through Discharging Door Showing Details of Discharger Link and Cam Mechanism and Sectional Details of Furnace Proper.

Table II
Thermal Efficiencies

Month	Operating Efficiency Per Cent	Net Thermal Efficiency Per Cent
February, 1927	96.2	66.9
March, 1927	96.7	70.8
April, 1927	96.87	67.4
Averages	96.59	68.4

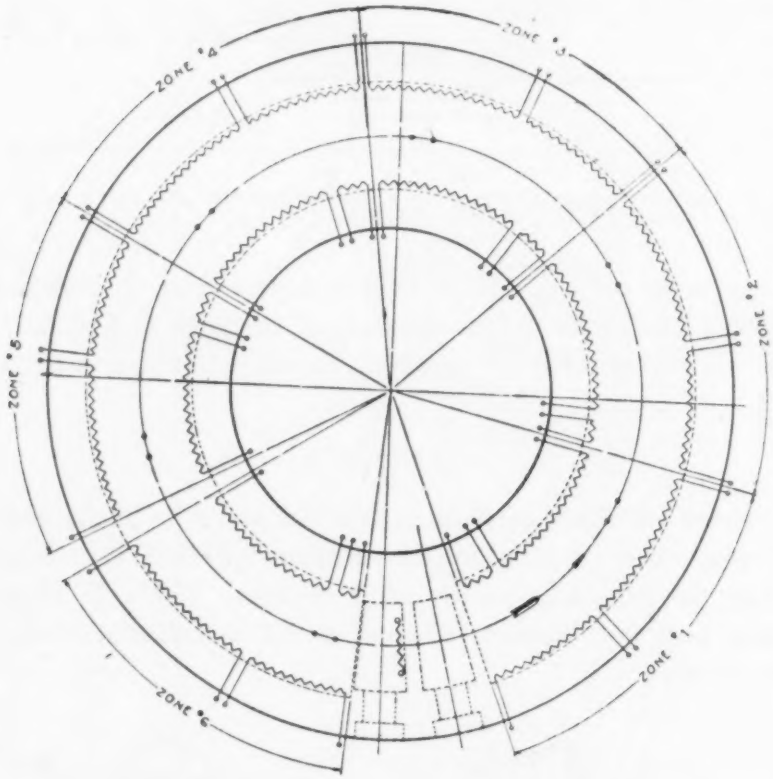


Fig. 9—Diagram Showing Division of Furnace Into Zones and Location of Furnace Heating Elements in Each Zone.

The net thermal efficiency figures include all radiation, transformer and standover losses, and are indicative of the actual power paid for. The operating efficiency was calculated on the basis of actual producing cycles to total possible cycles. There was no direct labor of any kind performed during the 3-month period.

Advantages

1. Makes possible the location of heat treating operations with-

other production operations, thereby making same a pace setter, because of its wide range of time cycles, for preceding and subsequent operations which makes possible economies in a sequence of other operations of a magnitude that makes the furnace investment a most desirable one, even though the actual economy in the heat treatment operation be small in itself.

2. Makes possible 100 per cent individual handling of product in the heat treating operation resulting in exact duplication of treatment on each individual part. This is vital if highest possible quality of product is to be secured.

3. Makes possible the complete elimination of direct labor on the heat treating operation and centralizes 100 per cent responsibility for results into the hands of one man. The importance of this cannot be over-estimated from a quality standpoint.

4. Makes possible maximum net thermal efficiency due to heating nothing but the product being heat treated.

5. Makes possible maximum production per square foot of floor space.

6. Makes possible maximum flexibility in that it can accommodate itself to the heat treatment of a variety of designs of parts and function with the same uniformity and efficiency on each.

7. Makes possible maximum life of furnace mechanism in that the design lends itself to rugged structural steel construction and that no parts of conveying mechanism are subjected to heat.

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

THE CONSTITUTION OF STEEL AND CAST IRON PART IX

By F. T. Sisco

Abstract

The present installment, the ninth of the series, takes up the formation of Graphite in Cast Iron and shows typical structures of gray iron containing graphite. The size and distribution of the graphite particles and the amount of cementite in the matrix are discussed in their relation to the physical properties of cast iron. Finally the theory of graphitization of cementite is viewed in its effect on the equilibrium diagram and the constitutional changes of the iron carbon alloys.

IN our discussion of the constitution of steel and cast iron, we have, up to this point, considered the iron-carbon series to be alloys of the pure metal iron and the definite chemical compound iron carbide, Fe_3C. Or, in metallographic terms, the iron-carbon series are alloys of ferrite and cementite. We have already noted that cementite is soluble in gamma iron up to the saturation point, or 25.5 per cent (equivalent to 1.7 per cent carbon). It is almost wholly insoluble in alpha iron, the allotropic form stable at atmospheric temperature. Hence in the iron-carbon alloys containing less than 1.70 per cent carbon we have, in their normal structural condition, ferrite and pearlite[92] or cementite and pearlite, depending whether the alloy contains less or more than 0.85 per cent carbon.

In the steels containing between 0.01 and 0.85 per cent carbon the cementite present is all in the pearlite, and so is known as eutectoid cementite. In the steels containing between 0.85 and 1.70

[92]The eutectoid or ferrite-cementite aggregate containing 0.85 per cent carbon. See TRANSACTIONS, Vol. X, page 467, September, 1926.

The author, F. T. Sisco, is Chief of Metallurgical Laboratories, Air Corps, War Department, Wright Field, Dayton, Ohio.

per cent carbon there is more cementite than is required for the pearlite consequently we have present (1) eutectoid cementite and (2) pro-eutectoid cementite.

When our alloy contains between 1.70 per cent and 4.30 per cent carbon there is more than 25.5 per cent cementite present. As gamma iron will not retain more than 25.5 per cent cementite in solution (saturated austenite) there will be some cementite in excess. In a previous installment we saw that this excess cementite forms an eutectic alloy with some of the saturated austenite. At atmospheric temperature the iron-carbon alloys containing between 1.70 per cent and 4.30 per cent carbon will contain (1) eutectoid cementite, (2) pro-euctectoid cementite and (3) eutectic cementite.

When the alloy contains more than 4.30 per cent carbon there is more cementite present than is necessary for the austenite-cementite eutectic. Hence at atmospheric temperature these alloys will contain (1) eutectoid cementite, (2) pro-eutectoid cementite, (3) eutectic cementite and (4) pro-eutectic cementite. It is necessary that we keep these four forms of cementite in mind as they enter importantly into the dissociation of iron carbide into iron and graphite.

The Formation of Graphite in Castings

In previous installments we have mentioned that cementite, under certain conditions, is relatively unstable, tending to dissociate according to the reaction:

$$Fe_3C \rightarrow 3Fe + C$$

In ordinary iron poured into castings most of the cementite does break up according to this reaction. There are two important factors promoting the formation of graphite, aside from the relative instability of the cementite. These are: (1) the presence of a considerable percentage of silicon in the iron and (2) a slow rate of cooling through the solidification range.

Most foundry irons contain a relatively large amount of silicon and as many of them are poured into castings of sufficient cross section so cooling is relatively slow, the finished casting will contain considerably more graphite and combined carbon (cementite). In the average casting the graphite and combined carbon will be approximately 3.00 and 0.60 per cent respectively. If a relatively

large amount of silicon, and slow cooling promote the formation of graphite, it follows that a small percentage of silicon and comparatively rapid chilling will promote the retention of combined carbon. It is also thought that much sulphur and manganese prevents the formation of graphite.

When a cast iron contains most of the carbon in the form of graphite it is known as gray iron. Due to the large volume occupied by the graphite flakes the fracture appears gray or grayish black. Some cast irons contain but a portion of the carbon in the form of graphite. A fracture of these irons will show dark areas where graphite is present; and shiny, light colored areas where little or no graphite is present. These irons which contain about half of the total carbon in the form of graphite and half as cementite are called mottled iron.

When cast iron contains practically no graphite, the fracture is white and shiny; it is then known as white cast iron. Our discussion of the constitution of the iron-carbon series in previous chapters has considered only the steel-white cast iron or metastable alloys. Gray cast irons comprise the bulk of foundry iron poured into commercial castings.

Structure of Gray Cast Iron

When cast iron contains most of the total carbon in the form of graphite, we should theoretically have a matrix that is similar in structure to a low carbon steel. In this matrix of ferrite will be embedded the graphite. Fig. 55 shows the appearance of a specimen of cast iron with a graphite content of 3.27 per cent and a combined carbon content of 0.15 per cent. If this specimen had been etched we would see the irregular, polyhedral grains of ferrite with which we became familiar when we studied the low carbon steels.

In Fig. 55 the graphite occurs as large curved plates or flakes. This specimen was taken from a commercial iron casting. The size and relative distribution of the graphite flakes may be called normal for commercial cast iron. In Fig. 56 is shown the appearance of a special gray iron. In this specimen which was taken from a high grade piston ring for an airplane engine, the graphite flakes are extremely small. Aside from the few rounded areas of graphite, the flakes as so small that they are scarcely discernible

at a magnification of 100 diameters. This structure is obtained by regulating the composition of the metal and by special methods of casting.

In Fig. 57 is shown still another typical structure of cast iron. In this specimen the individual graphite particles are extremely small but are segregated into areas of appreciable size. Fig. 58

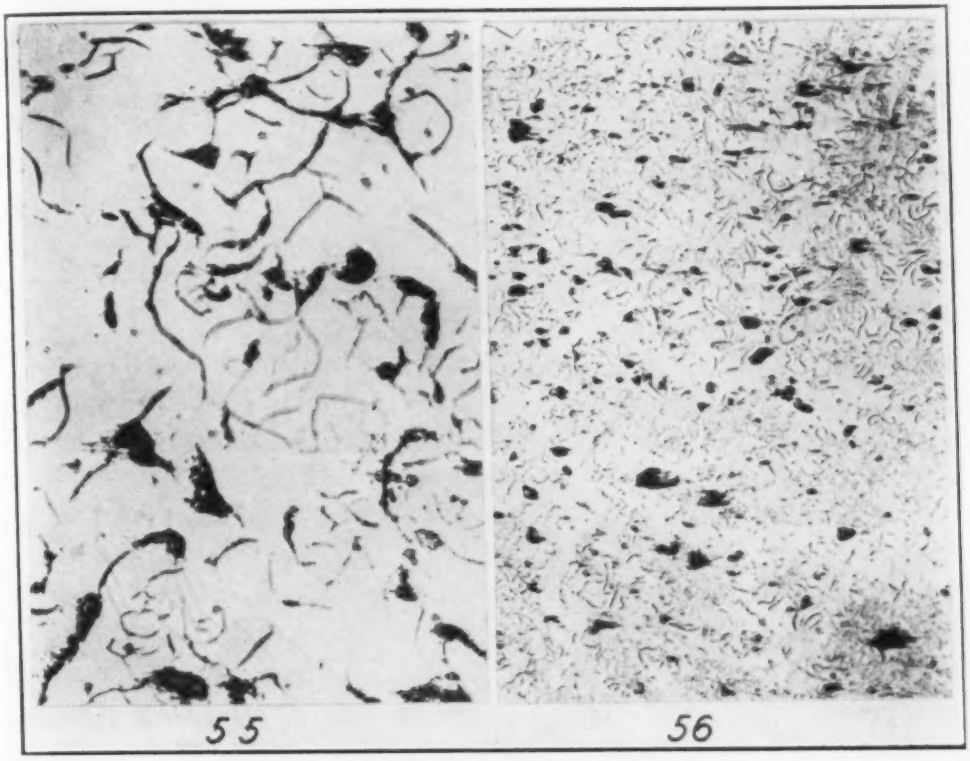


Fig. 55—Photomicrograph of Gray Cast Iron Showing Large Flakes of Graphite. Magnification 100 X, Unetched. Fig. 56—Photomicrograph of Gray Cast Iron Showing Very Small Flakes, and a few Rounded Particles of Graphite. Magnification 100 X, Unetched.

shows this same specimen at higher magnification and after etching. The white grains are ferrite, and the dark grains at the right are pearlite which contains the cementite. This photomicrograph shows in detail the distribution and size of the individual graphite flakes. As this cast iron contains 0.39 per cent combined carbon the matrix is equivalent in structure to a hypoeutectoid steel of 0.39 per cent carbon. Fig. 59 from Sauveur shows the structure of a cast iron containing approximately 0.90 per cent combined carbon. The structure consists of graphite flakes (black) embedded in a matrix of laminated pearlite.

In examining the structure of gray cast iron it should be re-

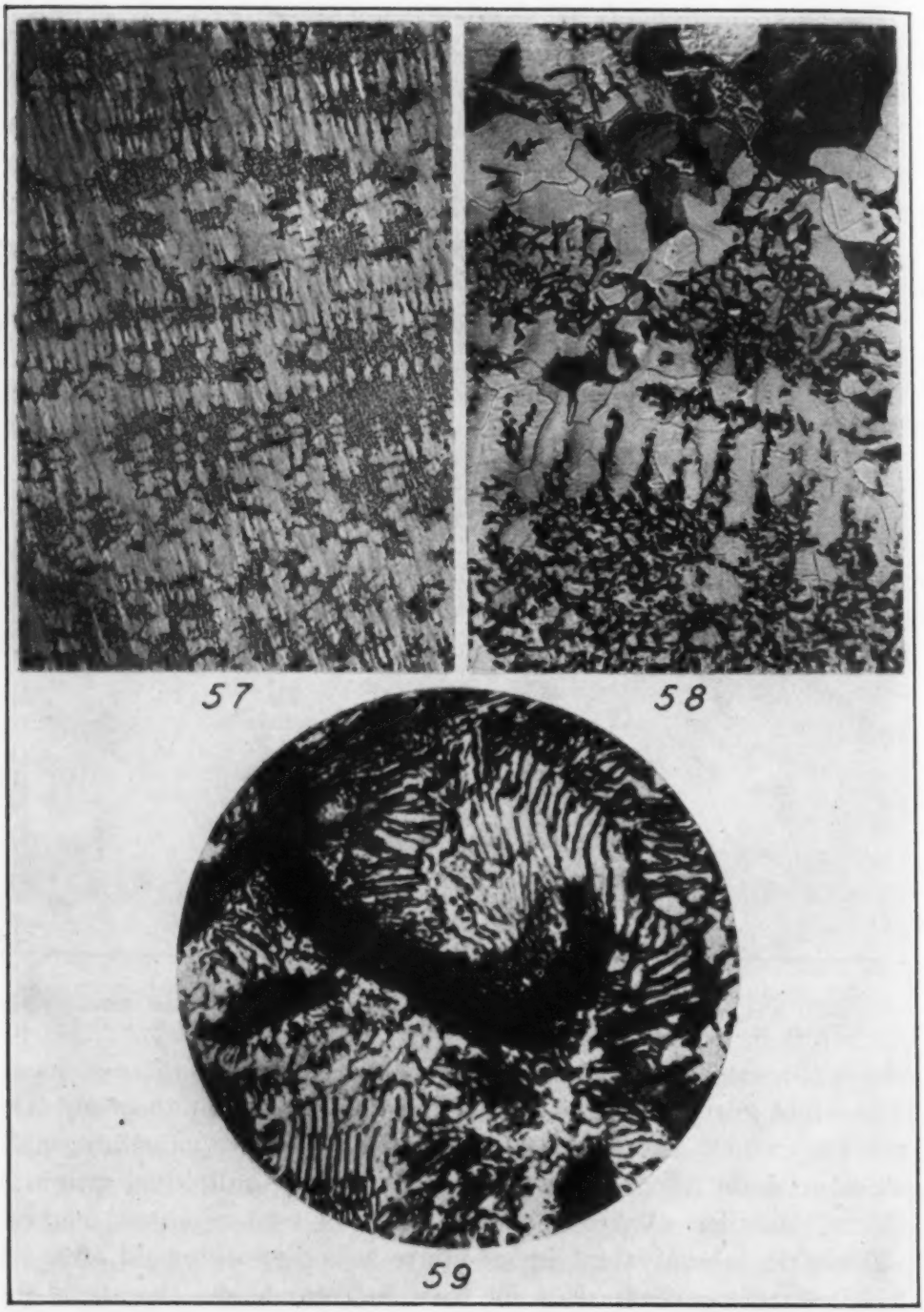


Fig. 57—Photomicrograph of Gray Cast Iron Showing Small Particles of Graphite Segregated into Large Areas. Magnification 100 X Unetched. Fig. 58—Photomicrograph of Gray Cast Iron Etched with Alcoholic Nitric Acid Showing a Hypereutectoid Matrix. Same as Fig. 57. Magnification 500 X. Ferrite Grains—white (center); Pearlite Grains—dark (right); Graphite in Small Flakes, Black (left and center). Fig. 59—Photomicrograph of Gray Cast Iron Showing Eutectoid Matrix. Magnification 630 X. (After Sauveur).

membered that graphite has a very low specific gravity, consequently it makes up a considerable bulk. A cast iron containing 3.00 per cent graphite by weight will contain about 12 per cent of the element by volume. This accounts for the relatively large area occupied by the graphite in Fig. 55.

Structure of Gray Cast Iron vs. Properties

Graphite has a great influence on the properties of iron. Graphite in itself is weak; also it breaks up the continuity and cohesion of the ferrite grains, thus producing brittleness. Gray iron is brittle, weak and cannot be worked or deformed, hot or cold. In other words, it is not malleable. It has, however, a fairly high compressive strength. Cast iron is usually soft and is readily machined. This combined with its low melting point and high fluidity makes it ideal for complicated casting and for castings that must be machined, but which do not have to withstand vibratory or impact stresses.

The weakness and brittleness of ordinary gray cast iron is due principally to the form of the graphite flakes; the structure illustrated in Fig. 55 representing an iron with comparatively poor properties, due to the large plates of graphite. If it were possible to pour molten iron into a mold so that all of the graphite would take the form of small rounded areas the properties would be much improved. The nearest approach to this is pouring the castings in hard white iron, and then graphitizing the cementite by an annealing treatment as in the production of malleable iron.

The properties of cast iron depend upon (1) the amount, shape and distribution of the graphite and (2) the properties of the matrix. We know that a steel containing 0.15 per cent carbon is not so strong as a steel containing 0.75 per cent carbon. It is thus obvious that if the matrix of a cast iron contains 0.75 per cent carbon the iron will be stronger than if it contained 0.15 per cent carbon.

It is usually necessary to have a casting that will machine readily and still have a fair amount of strength, hence most commercial castings contain between 0.30 and 0.60 per cent combined carbon or the equivalent of a medium carbon steel.

When it is desired to produce a gray iron casting with a hard surface to resist wear the solidification is regulated so that the

surface will chill more rapidly than the interior. This rapid chilling prevents excessive graphite formation near the surface. They are then known as chilled iron castings, and are extensively used for car wheels and chilled rolls for rolling mills. It is necessary to regulate the chemical composition of chilled castings carefully.

Theory of the Graphitization of Cementite

It is well known that cementite readily dissociates into iron and graphite when heated to a high temperature. The graphitizing of cementite in the production of malleable iron is based on this fact. It is also well known that the higher the temperature, the more rapidly and completely this dissociation takes place. Now, it is also generally assumed that the higher the temperature at which cementite is formed the more readily this cementite dissociates in cooling into ferrite and graphite. If this is the case, graphitization in the iron-carbon alloys will take place in the following order: (1) pro-eutectic cementite, present in iron-carbon alloys containing more than 4.30 per cent carbon; (2) eutectic cementite, present in iron-carbon alloys containing between 1.70 per cent and 4.30 per cent carbon and also in irons in which pro-eutectic cementite is present; (3) pro-eutectoid cementite present in iron-carbon alloys containing between 0.85 and 1.70 per cent carbon and also when eutectic and pro-eutectic cementite are present, and (4) eutectoid or pearlite cementite present in iron-carbon alloys containing between 0.01 and 0.85 per cent carbon, and also in all of the higher carbon alloys.

In hypereutectic cast irons the pro-eutectic cementite forms at relatively high temperature (see Fig. 45). At this temperature there is no tendency to stability for this excess cementite and it dissociates into iron and graphite almost as soon as formed.

With normal slow cooling, by the time the eutectic temperature is reached practically all of the pro-eutectic cementite has dissociated. At the eutectic temperature, eutectic cementite forms. This too readily breaks up into iron and graphite. Only an extremely accelerated cooling will prevent this dissociation. The graphite formed from the pro-eutectic cementite acts as nuclei for the acceleration of the dissociation of the eutectic cementite. With fairly slow cooling we can feel sure that all of the pro-eutectic and all of the eutectic cementite dissociates into iron and graphite.

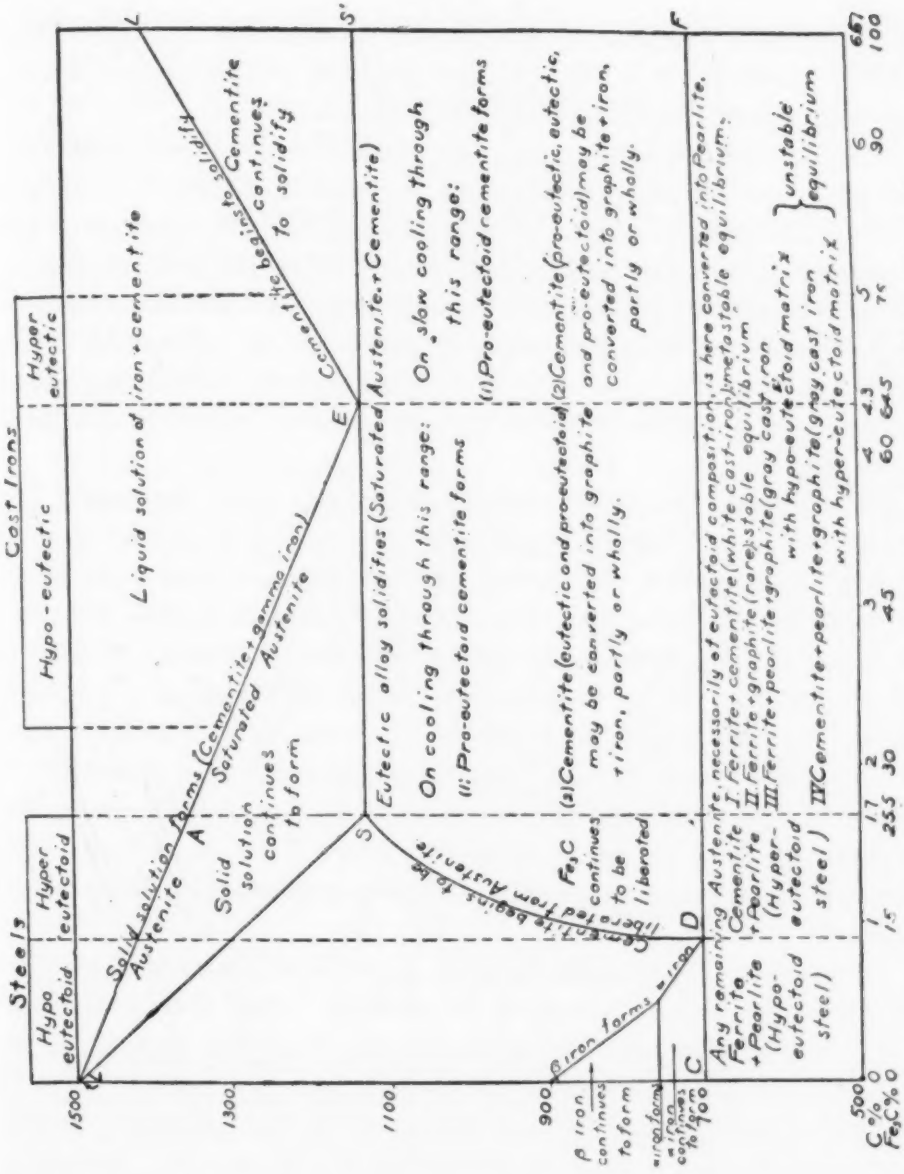


Fig. 45—Equilibrium Diagram of Iron-Carbon Alloys with Description (Sauveur).

Below the eutectic temperature, pro-eutectoid cementite begins to be expelled from the saturated austenite. As this pro-eutectoid cementite is formed at a relatively low temperature it dissociates less readily, but if cooling is retarded and if considerable silicon is present—most of it (usually practically all) will break up into iron and graphite.

When the metal has cooled to the eutectoid temperature (the transformation, $A_{3\text{-}2\text{-}1}$, range) the eutectoid cementite is expelled from the remaining austenite to make up the pearlite aggregate.

The temperature is now too low for the dissociation of much of this pearlite-cementite into the iron and graphite unless cooling is very slow and a large amount of silicon is present.

In the normal foundry iron the percentage of silicon is between 1.50 and 3.00 per cent, and cooling is usually sufficiently retarded in the solidification of the casting in a sand mold so that all of the pro-eutectic cementite (if any is present), all of the eutectic cementite, practically all of the pro-eutectoid cementite and a portion of the eutectoid cementite dissociates into iron and graphite. The result is a cast iron with a hypoeutectoid matrix; containing about 3.00 per cent graphite and 0.30 to 0.60 per cent carbon in the form of cementite.

The higher the carbon the more rapidly and completely the graphitization of cementite proceeds. In a cast iron 3.50 to 4.00 per cent total carbon the carbon will graphitize almost completely if conditions are favorable. On the other hand, in a steel containing 1.50 per cent carbon, the carbon will not graphitize at all except under unusual or exceptional conditions (such as very high silicon or prolonged annealing, etc.). From this it follows that for complete graphitization, nuclei of graphite are essential to accelerate dissociation of the pro-eutectoid or eutectoid cementite. In order to have nuclei of graphite present we must have free cementite at a temperature where almost spontaneous dissociation will occur.

In other words in order to have a practically complete graphitization eutectic-cementite must be present. This means that the carbon in the alloy must be approximately 2.50 per cent or more. If we have an iron containing about 3.50 per cent carbon there is sufficient eutectic cementite so dissociation of this cementite occurs spontaneously at the high temperature where eutectic cementite is formed. These graphite particles formed from the eutectic cementite act as nuclei for the graphitization of the pro-eutectoid and eutectoid cementite which are formed at much lower temperature. The tendency for graphitization to occur when eutectic cementite is present is so great that drastic methods are necessary to prevent it.

On the other hand, if there is no eutectic cementite present as in the case of iron-carbon alloys containing 1.70 per cent carbon or less, there will be practically no spontaneous graphitization and

no graphite particles formed at a high temperature to act as nuclei for further dissociation. Hence in the case of these alloys containing less than 1.70 per cent carbon drastic methods are necessary to have any graphite formed.

Iron-Graphite Equilibrium Diagram

Some writers dispute the theory that cementite first forms as the iron-carbon alloys solidify; and that this cementite in the case of the high carbon alloys dissociates almost spontaneously according to the reaction

$$Fe_3C \rightarrow 3Fe + C$$

These writers among whom are Charpy, Heyn and Benedicks, believe that graphite forms directly. They maintain that instead

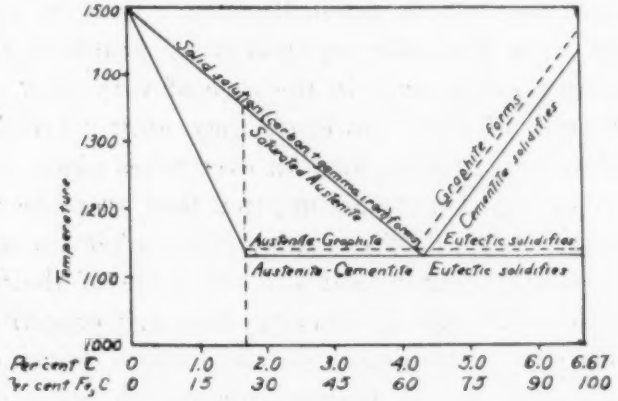


Fig. 60—Combined Graphite, Cementite Equilibrium Diagram of Iron-Carbon Alloys.

of having an austenite-cementite eutectic, the eutectic is austenite-graphite and austenite-cementite. Fig. 60 taken from Sauveur's text[93] shows the combined equilibrium digaram of the iron-carbon alloys based on this assumption. From this diagram it is evident that the temperatures of graphite formation and of the solidification of the austenite-graphite eutectic are slightly higher than for the ausenite-cementite alloys. It is reasoned that the formation of the metastable cementite is due to under-cooling.

It is probable that even though graphite is the stable form of carbon in the high carbon alloys, this graphite is never formed directly but on the other hand, is the result of the dissociation of the metastable cementite which is formed first.

[93]Metallography and Heat Treatment of Iron and Steel, 1926, page 430.

Concerning this Sauveur states[94]

> "Although recognizing the fact that graphite and not cementite must be the final condition assumed by carbon, the author believes with some other observers that graphite never forms directly as iron-carbon alloys solidify, its occurrence always resulting from the breaking up of cementite according to the reaction
>
> $$Fe_3C \rightarrow 3Fe + C$$
>
> from which it would follow that the iron-graphite fusibility curve need not be included in the equilibrium diagram. Even those who believe in the possibility of the direct formation of graphite do not deny that cementite is the constituent which generally forms first on solidification; they state that the separation of graphite from molten iron is possible only in the case of very slow cooling. As a matter of fact, however, they offer no conclusive evidences that such separation ever takes place,..... ..... On the assumption that graphite results from the breaking up of cementite soon after its solidification, it is readily understood why, in spite of their very great difference in specific gravity, iron and graphite are found uniformly distributed in the various parts of castings. The microscopical examination of the structure of very slowly cooled castings does not reveal the existence of a graphite-austenite eutectic."

For our study of the constitution of the iron-carbon alloys we will be safe in assuming that the graphite found in gray cast iron is the result of the dissociation of the metastable cementite formed when the iron carbon alloys solidify.

Fig. 45 reproduced from a previous installment gives the complete equilibrium diagram of the iron-carbon alloys with a description of the constitutional changes taking place. From what we have learned concerning the behavior of the iron-carbon alloys when they cool from above the melting point to atmospheric temperature we should now be able to look at this diagram as whole understanding clearly how each change takes place.

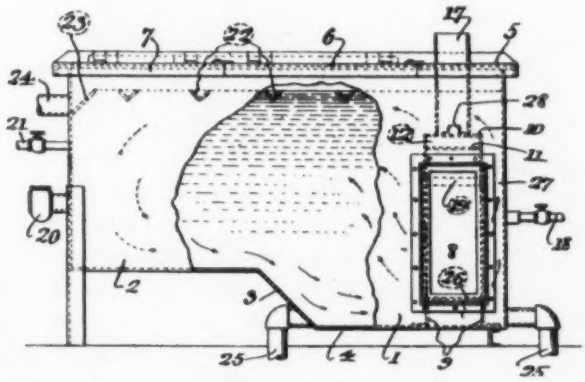
[94]Loc. Cit., page 430.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,624,982, Apparatus for Cleaning Metal Parts, Louis Rosenberg, of Milwaukee, Wisconsin.

This patent describes an apparatus for cleaning metal parts, which comprises a tank 1 having an elevated bottom 2, an inclined bottom 3 and a lowered bottom 4. A heater 8 is provided adjacent to one end of the tank and a plurality of lugs 22 adjacent to the top to support the metal articles to be cleaned. An inlet 18 is provided in the end of the tank adjacent to the heater 8, and an outlet 24 at the opposite end with a suitable skimmer 23. In the operation of the device, the tank is filled with water, the desired chemicals added and the metal parts placed on the supporting lugs 22. The circulation of the cleaning fluid is indicated by the arrows in the accompanying figure passing entirely around the heating chamber 8, thence along the top of the tank and returning along the elevated bottom 2 and inclined bottom 3. A steam pipe 21 for agitating the contents of the tank is provided and the lid is divided into three sections 5, 6 and 7, which are preferably hinged to the container.



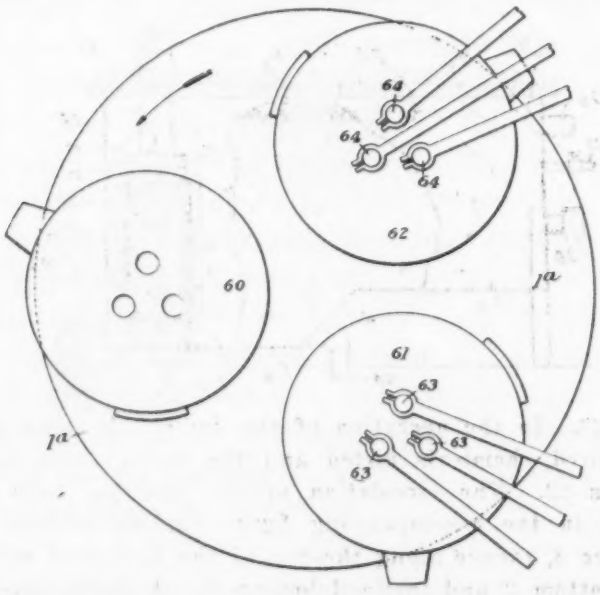
1,625,524, Manufacture of Steel Sheets, William E. Caugherty, of Natrona,, Pennsylvania, Assignor, by Mesne Assignments, to Allegheny Steel Company, of Brackenridge, Pennsylvania, a corporation of Pennsylvania.

This patent describes and claims a method of manufacturing steel sheets for difficult drawing or stamping operations. It is the object of the invention to provide a method of rolling steel sheets which will have the advantages of both the present tight and loose rolling methods without the disadvantages of either. In carrying out the method, the sheets are roughed down to approximately one-half their finished length and then singly annealed in a standard "blue-anneal" furnace operated con-

tinuously at a temperature sufficiently high to completely normalize the structure. The sheets are then pickled, dipped in an emulsion of charcoal and water and then matched, raised to a relatively low rolling temperature and rolled to length. The relatively final rolling temperature does not distort the grain structure produced by the annealing operation because of the sheets being approximately one-half the finished length. The work in the final rolling operation is necessarily slight. After the final rolling, the sheets are again pickled and the box annealed.

1,626,263, Furnace and Method of Operating the Same, Frank W. Brooke, of Pittsburgh, Pennsylvania, Assignor to William Swindell and Brothers, of Pittsburgh, Pennsylvania, a corporation of Pennsylvania.

This patent describes an electric furnace and method of operating the same in which a plurality of furnaces are used with one electrical equipment, the installation being such that it is possible to provide a

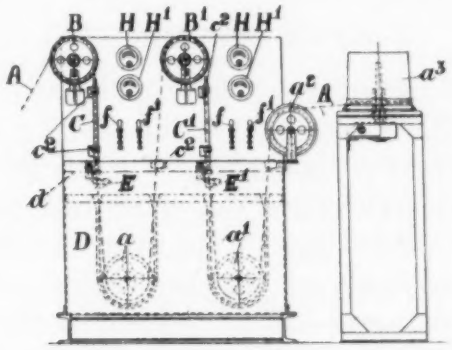


relative movement between the electrical equipment and the furnace. With this construction one furnace may be tapped, repaired and recharged, while a charge is melted in another furnace, thereby increasing the efficiency of the single electrical equipment. In the embodiment of the invention shown in the accompanying figure, three furnaces 60, 61 and 62 are carried by a turntable 1a, a suitable tilting mechanism etc. being provided, and two electrical units carrying electrodes 63 and 64 of substantially similar construction are provided. The furnaces are located at substantially 120 degrees apart on the turntable and rotation of the table 8 will bring a freshly charged furnace into engagement with the electrodes 63 and move the furnace previously in engagement with the electrodes 63 to a position under the electrodes 64 wherein the partially melted charge may be completely melted. The next rotation will move the melted charge into position for tapping. The furnace may then

be repaired and recharged and the cycle repeated. Various modifications in design and construction are shown in the patent.

1,626,713, Apparatus for the Electric-Heat Treatment of Wire, Strip, and the Like, Herbert Alexander and Arthur Imbery, of Leeds, England.

This patent describes an electric heat treatment apparatus for a wire, strip, or the like, in which the wire **A** is passed over an upper electrical contact **B** and then through a refractory tube **c**, the lower end of which



dips into a liquid **d** in a quenching bath **D**. The wire is then passed over a lower contact **E** which is immersed in the quenching bath and thence under a pulley **a** near the bottom of the bath, then over a second upper contact **B-1** and again through the bath under a second pulley **a-1**. The apparatus may be constructed to handle any number of strands of wire in parallel position and as each wire is under individual control, the degree of heating may be varied so as to accommodate wires of different gage in the same apparatus.

1,628,281, Process of Making Basic Open-Hearth Steel, Julian L. Schueler, of Peoria, Illinois.

This patent describes a process of making a basic open-hearth steel wherein the original charge does not contain sufficient limestone to form a finished slag with respect to the amount of metal charged, melting this charge and adding burned lime to bring the slag up to the proper consistency, after which the addition alloying materials may be added and the heat is ready to tap. Due to the reduced amount of stone in the original charge, less carbon and less heat are necessary to melt the charge, so that a considerable reduction in fuel economy is made.

1,626,248, Alloy, Paul D. Merica, of Westfield, and James S. Vanick, of Elizabeth, New Jersey, Assignors to The International Nickel Company, of New York, N. Y., a corporation of New Jersey.

This patent describes an alloy cast iron, particularly adapted to resist oxidation and corrosion. The alloy is produced by adding nickel and chromium as alloying metals to gray cast iron to produce an alloy which can be cast in sand molds or against a chill. In making the alloy, cast iron having a carbon content of 2 to 4 per cent has added to it nickel in amounts of 5 to 35 per cent and chromium from 2 to 15 per cent. The

alloy is of a slightly greater shrinkage than ordinary cast iron but the shrinkage is not sufficient to prevent the formation of good castings. The corrosion resistance of a typical casting is such that in 5 per cent sulphuric acid corrosion was found to be 536 milligrams per square decimeter per day.

COMPARISON OF THE ALLOYING ELEMENTS CHROMIUM, NICKEL, MOLYBDENUM AND VANADIUM IN STRUCTURAL STEELS

(Continued from Page 884)

size a number of features which have not always been given adequate consideration. No one of the four alloying elements selected for this discussion and no one group of steels has a monopoly on all of the desirable properties for structural purposes. While there is a practical interchangeability in mechanical properties in the low alloy content steels certain characteristics in their making, shaping, treating, etc., may make it advantageous to select a particular steel from one or another group for each of two services which at first sight might appear quite similar. It is this ability to select the type of steel which will meet requirements at least cost that has so largely contributed to the success of mass production in the United States.

Comparisons have rightly been made on the basis of chemical composition, for this is important; it does not, however, tell all the story. Of perhaps greater importance is the "quality" factor or those characteristics, other than the proportions of carbon and alloying elements present, which contribute so largely to the suitability of steels for a given purpose. With both the "quality" factor and the chemical composition under control many advances have been made in the solution of the engineering problems of construction. Pride may rightly be had for the past, but continued efforts will be needed to meet the future severe requirements of engineers involving fatigue, corrosion, high temperatures, and wear.

So far as can be forseen at this time, at least three of the elements selected for discussion, namely chromium, nickel and molybdenum, and possibly all four, will play an important part in these developments. Evidence to this effect is already at hand in the current high alloy content steels briefly described.

THE ENGINEERING INDEX

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Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each month with a specially prepared section of The Engineering Index. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the copy prepared for the annual volume of the Index published by the A. S. M. E.

In the preparation of the Index by the staff of the A. S. M. E. some 1,200 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. will be supplied with a selective index to those articles which deal particularly with steel treating and related subjects.

Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders. A separate print is required for each page of the larger periodicals, but whenever possible two pages will be photographed together on the same print. When ordering prints, identify the article by quoting from the Index item: (1) Title of article; (2) name of periodical in which it appeared; (3) volume, number, and date of publication of periodical; and (4) page numbers.

ALLOY STEELS

MOLYBDENUM IN. Molybdenum in Alloy Steels. Metallurgist (Supp. to Engineer), Apr. 20, 1927, pp. 51-52. Review of report by J. A. Jones of Research Department, Woolwich, on influence of molybdenum on medium-carbon steels containing nickel, chromium, dealing with wide range of steels to which molybdenum has been added; report confirms Gillett and Mack's work in establishing definite field of utility for molybdenum as additional constituent of alloy steels; outstanding feature among properties of nickel-chromium-molybdenum steels is relative absence of mass effect shown by uniformity of properties through thickness of large forgings after treatment.

RAILWAYS. Alloy Steels in the Railroads, F. J. Griffiths. Ry. Club of Pittsburgh—Official Proc., vol. 26, no. 5, Mar. 24, 1927, pp. 94-98 and (discussion), 98-116. Use of high-manganese rails; vanadium steel in locomotive frames, side arms, rods and pins; leaf springs which were formerly made of carbon steel are now made of silico-manganese or of chromium-vanadium; alloy steel bearings for railroad cars; heat-treated alloy steels in staybolts and engine bolts; alloys used for sake of resistance to corrosion.

ALLOYS

COBALT-TUNGSTEN. Binary System Cobalt-Tungsten (Zur Kenntnis des Zweistoffsystems Kobalt-Wolfram), W. Geib and J. A. M. van Liempt. Zeit. für Metallkunde, vol. 19, no. 3, Mar. 1927, pp. 113-114, 3 figs. Investigation of system with aid of measurements of temperature of coefficients; this system forms no complete crystal series.

ELASTICITY AND VISCOSITY. Elastic and Viscous Properties of Alloys (Les Proprietes elastiques et visqueuses des alliages), M. Chevenard. Societe des Ingenieurs Civils de France—Proces-Verbal, no. 6, Apr. 8, 1927, pp. 134-140 and (discussion) 140-142. Moduli of elasticity and internal friction; influence of temperature, composition, cold working and hardening; isothermal viscosity; viscosity at increasing temperature.

LIMITING STATE. Possibility of Visualizing Existence of Limiting States in the Study of Alloys (Possibilité d'envisager l'existence d'états limites dans l'etude des alliages), L. Grenet. Revue de Métallurgie, vol. 24, no. 2, Feb. 1927, pp. 93-107, 22 figs. Study of diagram of equilibrium from which existence of limiting states can be deduced.

LOW-MELTING. Transformation Phenomena of Low-Melting Alloys (Rose's metal) (Umwandlungserscheinungen bei leicht schmelzbaren Legierungen (Rosesches Metall), R. Fleischmann. Zeit. für Physik, vol. 41, no. 1, 1927, pp. 8-17, 8 figs. Investigated tin-lead-bismuth alloy is shown, by dilatometric and resistance measurements, to exist in three different modifications; thermoelectric experiments on alloy confirm these results. Brief translated abstract in Brit. Chem. Abstracts, Mar. 1927, p. 195.

ALUMINUM

CASTINGS. Aluminum Castings Crown Pittsburgh Shrine, W. H. Lloyd and E. Bremer. Foundry, vol. 55, no. 8, Apr. 15, 1927, pp. 292-296 and 321, 13 figs. One of best illustrations of use of aluminum castings for ornamental architectural decoration is in construction of spire for Pittsburgh church; total of 221 castings are used in construction; patterns for castings were made by General Model & Pattern Co., Cleveland; spire is constructed of alternate panels; dry sand cores were used to form carved sections at tips of projecting parts; all castings were made from alloy containing 5 per cent silicon and 95 per cent aluminum, having minimum tensile strength of 17,000 lbs.

CORROSION. Relation of Corrosion of Aluminum to its Physical and Chemical Properties (Die Abhängigkeit der Korrosionsursachen des Aluminums von seiner physikalischen und chemischen Beschaffenheit), E. Maab. Korrosion und Metallschutz, vol. 3, no. 2, pp. 25-30, 7 figs. Author shows that resistance of aluminum is in a great degree dependent upon its physical and chemical properties.

ELECTRIC CONDUCTIVITY. Electric Conductivity of Pure Aluminum (Die elektrische Leitfähigkeit des Reinaluminiums), M. Bosshard. Schweiz. Elektrotechnischer Verein—Bul., vol. 18, no. 3, 1927, pp. 113-122, 19 figs. Results of series of systematic investigations, showing influence of small admixtures of iron, silicon, titanium, copper, zinc, and calcium on conductivity of aluminum; shows also influence of heat treatment and cold working on conductivity.

ORGANIC-CHEMISTRY INDUSTRY. The Use of Aluminum in Organic Chemistry (Aluminium als Werkstoff in der organischen Chemie. Buschlinger. Zeit. für Metallkunde, vol. 19, nos. 1 and 3, Jan. and Mar. 1927, pp. 25-36 and 101-106, 6 figs. Review of experimental results in chemical industry, giving, it is claimed, for first time systematically arranged basic requirements for use of light metals; tests applied to coal-gas, petroleum, fermentation, fatty-acids, sugar, foodstuff and other industries.

PREPARATION AND USES. Light Metals (De lette metaller), S. Kloumann. Teknisk Tidskrift, vol. 57, nos. 15 and 16, Apr. 16 and 23, 1927, pp. 122-127 and 129-133, 14 figs. Describes different kinds of light metals, especially aluminum, its use in automobiles, railway cars, busses, tanks, and widespread use in manufacture of kitchen utensils; deals also with beryllium and magnesium.

STRUCTURE. Structure and Strength Properties of Very Pure Aluminum (Gefüge und Festigkeitseigenschaften von sehr reinem Aluminium), F. v. Göler and G. Sachs. Zeit. für Metallkunde, vol. 19, no. 3, Mar. 1927, pp. 90-94, 13 figs. Investigations show that 99.9 per cent aluminum has less strength than aluminum of less degree of purity; it has greater dilatation; complete recrystallization of cold-worked material occurs with all species of aluminum after annealing above 259 degrees; 99.9 per cent aluminum becomes very coarse-grained with annealing above 400 degrees; less pure aluminum only becomes coarse-grained after annealing above 600 degrees Cent.

ALUMINUM ALLOYS

AIRCRAFT INDUSTRY. U. S. Aircraft Industry Developing into Important Factor in Aluminum and Light Alloys. Am. Metal Market, vol. 34, no. 75, Apr. 19, 1927, pp. 3-5, 7 figs. Presents replies to questionnaire sent out to producers of aircraft, showing extent and nature of aluminum consumption at present time; there is belief in engineering circles that all-metal type will be generally adopted, owing to numerous advantages gained in operation by reason of strong and light qualities of duralumin.

ALUMINUM-SILICON. Solubility of Silicon in Aluminum—Addition to Diagram of State Aluminum-Silicon (Ueber die Löslichkeit des Siliziums im Aluminium), W. Köster and J. Müller. Zeit. für Metallkunde, vol. 19, no. 2, Feb. 1927, pp. 52-57, 10 figs. Curve of solubility of silicon in this system; influence of degree of distribution of silicon on analytical results and on hardness.

CALCIUM, INFLUENCE OF. The Influence of Calcium on Aluminium Containing Silicon, J. D. Grogan. Metal Industry (Lond.), vol. 30, no. 15, Apr. 15, 1927, pp. 383-385, 4 figs. Results of investigations; on addition of calcium to aluminium compound $CaAl_2$ appears completely soluble in molten aluminium within range examined, but very slightly soluble in solid aluminium; on addition of silicon to this alloy compound $CaSi_2$ is formed, completely soluble in molten aluminium; in solid aluminium solubility is extremely small at all temperatures. Abstract of paper read before Inst. of Metals.

CONSTRUCTAL. Aluminum Alloys (Aluminium und seine Legierungen), K. L. Meissner. Zeit. für angewandte Chemie, vol. 40, no. 2, Jan. 13, 1927, pp. 61-62. Constructal 2 and constructal 8 are described and compared with duralumin; effect of various alloying metals with respect to tensile strength, elongation, hardness, etc.

TECHNICAL IMPORTANCE. The Significance of Aluminum as Raw Material in German Industry (Die Bedeutung des Aluminiums als Werskstoff für die deutsche Wirtschaft), H. Groeck. Maschinenbau, vol. 6, no. 4, Feb. 17, 1927, pp. 201-202. Total production of aluminum, measured in volumetric units, amounts at present to one-half of copper production; productivity of German works takes second place in world industry; through discovery of aluminum alloys and methods of improving them, a high-grade material is available, development of which deserves closest attention.

TECHNICAL IMPORTANCE. Aluminum Alloys and Their Technical Importance (Ueber Aluminiumlegierungen und ihre Bedeutung für die Technik), W. Haas. Centralblatt der Hütten u. Walzwerke, vol. 31, no. 10, Mar. 9, 1927, pp. 115-117. Deals with binary alloys including aluminum-copper, aluminum-zinc, aluminum-silicon and aluminum-manganese alloys; most important ternary alloy is duralumin, but in recent years number of similar alloys have been placed on market; refers to process developed by Strasser Bros. in Switzerland, for producing aluminum alloys which, without refining, possess sufficiently high strength; electric purification process.

ZINC-ALUMINUM. Change of Zinc-Aluminum Alloys in Solid State (Umwandlung von Zink-Aluminiumlegierungen im festen Zustand), W. Fraenkel and J. Spanner. Zeit. für Metallkunde, vol. 19, no. 2, Feb. 1927, pp. 58-60, 2 figs. Influence of small additions of other metals on velocity and transformation; results of tests.

BEARING METALS

PIPES AND BLOWHOLES. Prevention of Pipes and Blowholes in the Castings of Journal Brasses (Ueber Massnahmen zur Vermeidung von Lunkern und Poren beim Ausgiessen von Lagerschalen), H. Bellag. Motorwagen, vol. 30, no. 8, Feb. 20, 1927, pp. 97-98, 6 figs. Discusses different methods,

most important of which are those of which a certain arbitrary control of solidification is characteristic.

BLAST FURNACES

HOT STOVES, BRICKS FOR. Spiral Bricks for Hot Stoves, J. Tornblad. Iron & Coal Trades Rev., vol. 114, no. 3082, Mar. 25, 1927, p. 483, 1 fig. New type of checker bricks, so-called spiral bricks (Hartmann patents) which are manufactured in three sizes; among advantages claimed are that every part of surface partakes equally in heat storage; surface area of bricks is comparatively large; weight of bricks per unit volume of checkerwork is considerably less than with other types, etc.; gives results obtained at Ilsede Iron Works, Germany. See also Foundry Trade Jl., vol. 35, no. 554, Mar. 31, 1927, pp. 277-278, 1 fig.

OXIDATION PROCESSES. The Influence of Oxidation Processes in the Blast Furnace, F. Wüst. Iron & Coal Trades Rev., vol. 114, no. 3082, Mar. 25, 1927, pp. 480-481, 3 figs. Reoxidation of iron in front of tuyeres is of wholly unexpected importance; surprising results attained by use of hot blast and more recently of dried air are due to diminution in oxidation zone in front of tuyeres; there can be no escaping from conclusion that in usual blast-furnace practice, considerable hitherto unsuspected portion of iron already reduced, is reoxidized to extent which must seriously prejudice economy of process; author compares extent of oxidizing zone in three furnaces; full advantage of wider hearths can only be realized if volume of blast is increased in greater ratio than size of hearth; how further improvements can easily be effected in design and working of blast furnaces. Translated from Stahl und Eisen. See also translation in Foundry Trade Jl., vol. 35, no. 554, Mar. 31, 1927, pp. 279-281, 2 figs.

WATER GAS AS FUEL. A New Blast Furnace Process, P. W. Uhlmann. Blast Furnace & Steel Plant, vol. 15, no. 4, Apr. 1927, pp. 177-179. Author suggests use of water gas as fuel instead of coal or coke. Translated from Chemiker Zeit., vol. 51, Jan. 15, 1927, p. 37. See ref. to original article in Eng. Index Sec. A. S. S. T. Trans., p. 645.

BOILER PLATE

ANNEALING. The Annealing of Boiler Plate (Contribution à l'etude du recuit des toles pour chaudières), S. P. Wologdine. Revue de Métallurgie, vol. 24, no. 2, Feb. 1927, pp. 64-67, 9 figs. Results of author's study; points out that distribution of stresses can vary greatly and depends on conditions of deformation. Translated from Russian.

BRASS

COPPER RECOVERY FROM. Electrolytic Working of Brass Cuttings in Hydrochloric Acid Solution (Die elektrolytische Verarbeitung von Messingabfällen in salzsaurer Lösung), W. W. Stender. Zeit. für anorganische und allgemeine Chemie, vol. 159, no. 1-2, Dec. 22, 1926, pp. 145-157, 7 figs. Difficulties of recovering copper electrolytically from brass on commercial scale; possible methods of procedure; solution of problem is found in electrolysis of brass in hydrochloric acid solution. See brief translated abstract in Chem. & Industry, vol. 46, no. 13, Apr. 1, 1927, p. 223.

HOT BRITTLENESS. Hot Brittleness of Brass (Die Warmsprödigkeit von Messing), R. Mailänder. Zeit. für Metallkunde, vol. 19, no. 2, Feb. 1927, pp. 44-51, 18 figs. Brittleness of brass at high temperatures as examined; that brittleness of brass is function of temperature is shown by fact that after quenching from 500 deg. metal behaves normally in test; addition of small quantities of lead to brass intensifies brittle behavior of metal at high temperatures; results indicate that sudden heating of severely cold-rolled brass may lead to development of internal cracks. See brief translated abstract in Chem. & Industry, vol. 46, no. 15, Apr. 15, 1927, p. 255.

BRASS FOUNDRIES

AMERICAN FURNACES. American Furnace Practice for Brass Foundries, H. M. St. John. Metal Industry (Lond.), vol. 30, no. 15, Apr. 15, 1927, pp. 386-388. Factors affecting refractory performance; furnaces using solid fuel; crucible furnaces using oil or gas; open-flame furnaces; indirect-arc electric furnaces; induction furnace; high rate of production favorable; art of patching.

BRONZES

BEARING-METAL. Bearing Metal Bronzes, H. J. Roast and F. Newell. Eng. Jl., vol. 10, no. 4, Apr. 1927, pp. 213-221, 35 figs. Essential constants of bronzes in every-day use as determined by series of tests with metals carried out under practical working conditions.

CAR WHEELS

CHILLED. Chilled Wheels Made in the Sakako Works, T. Sugawara. Dept. of Railways (Japan)—Bul., vol. 15, no. 3, Mar. 1927, pp. 365-383, 8 figs. Advantages of chilled wheels. (In Japanese.)

ROLLED-STEEL. Great Industrial Economies Profitable in Plants of the Bethlehem Steel Company, G. A. Richardson. Central Ry. Club of Buffalo, N. Y.—Off. Proc., vol. 35, no. 2, Apr. 1927, pp. 2303-2307. Results obtained in manufacture of solid rolled-steel car wheels; steps in manufacturing; inspection and machining.

CAST IRON

ANNEALED. Mechanical and Machining Properties of an Annealed Cast Iron, G. C. Priester and F. J. Curran. Am. Soc. for Steel Treating—Trans., vol. 11, no. 5, May 1927, pp. 741-759 and (discussion) 759-762, 9 figs. Results of study of machining and mechanical properties of cast iron used in manufacture of pistons when subjected to various annealing temperatures; machining properties of annealed pistons were studied in modern production plant and various processes are described; results of heat treatment, chemical analysis, machining properties, transverse tests, tensile and hardness tests, compressive and shear tests and effect of time on annealing; microstructure of test bars are shown in photomicrographs.

CONSTITUTION. The Constitution of Steel and Cast Iron, F. T. Sisco. Am. Soc.

for Steel Treating—Trans., vol. 11, no. 4, Apr. 1927, pp. 626-635. Discusses constitution of iron-carbon alloys containing 4.30 to 6.67 per cent carbon; constitutional changes in this series when cooled from molten state to atmospheric temperature; behavior of whole series of iron-carbon alloys containing 0.01 to 6.67 per cent carbon, in cooling from high temperature, is reviewed.

HIGH-GRADE. Cast Iron for Machine Construction and Improvements in Melting Practice in Iron Foundries (Gusseisen für den Maschinenbau und Neuerungen im Schmelzbetrieb der Eisengiesserei), J. Mehrtens. Maschinenbau, vol. 6, no. 4, Feb. 17, 1927, pp. 196-201, 1 fig. Definition of high-grade cast iron; standardization work in the foundry; classification of cast iron according to quality; chemical composition; melting-furnace practice; furnaces for high-grade cast iron; after-treatment of molten iron; design of castings.

HIGH TEMPERATURE, EFFECT OF. The Influence of High Temperatures on the Texture and the Mechanical Properties of Cast Iron. Foundry Trade Jl., vol. 35, no. 555, Apr. 7, 1927, pp. 303-304, 1 fig. Piwowarsky's results are confirmed by 13 series out of 15.

MOLTEN. Play and Surface of Molten Cast Iron with Regard to its Analysis (Beobachtungen über das Spiel und die Oberfläche flüssigen Gusseisens in Bezug auf dessen Analyse), Zeit. für die Gesamte Giessereipraxis, vol. 48, no. 15, Apr. 10, 1927, pp. 121-124, 15 figs. Shows that content of foreign substances has considerable influence on behavior and appearance of molten iron in ladle.

OXYGEN IN. Oxygen in Pig and Cast Iron (Ueber den Sauerstoff im Roh- und Gusseisen), P. Oberhoffer and E. Piwowarsky. Stahl u. Eisen, vol. 47, no. 13, Mar. 31, 1927, pp. 521-533, 5 figs. Oxygen determinations in cast iron gave, as upper permissible limit, a content of 0.045 per cent O_2; results show, furthermore, that greater air volumes can be admitted to cupola than are generally customary, thus increasing furnace efficiency, thermal efficiency and iron temperature; relation between oxygen and silicon content; influence on oxygen of strength. See also Giesserei, vol. 14, no. 13, Mar. 28, 1927, pp. 197-202, 1 fig.

PHOSPHIDE EUTECTOID. The Effect of Prolonged Annealing on Phosphide Eutectoid (Die Einwirkung langer Glühzeiten auf das Phosphideutektikum), H. Pinsl. Stahl u. Eisen, vol. 47, no. 13, Mar. 31, 1927, pp. 537-540, 7 figs. Gives two examples illustrating behavior of iron phosphide under influence of annealing; shows that through prolonged annealing phosphide eutectoid of gray cast iron can be overcome by diffusion of phosphide in iron.

CASTING

CENTRIFUGAL. Centrifugal Casting of Steel, L. Cammen. Can. Machy., vol. 37, nos. 10, 11, 12, 13 and 14, Mar. 10, 17, 24, 31 and Apr. 7, 1927, pp. 32-33, 34-36, 20-21, 22-24 and 35 and 48-50, 7 figs. Deals with centrifugal tube casting and shows its present and prospective field of application and limitations, particularly where centrifugal tube casting comes into competition with piercing process. Paper read before Am. Soc. Steel Treating.

CENTRIGUGAL. On Centrifugal Casting, T. Sugawara. Dept. of Railways (Japan)—Bul., vol. 15, no. 3, Mar. 1927, pp. 338-364, 33 figs. (In Japanese.)

CHROMIUM-NICKEL STEEL

PROPERTIES AND HEAT TREATMENT. Facts and Principles Concerning Steel and Heat Treatment, H. B. Knowlton. Am. Soc. for Steel Treating—Trans., vol. 11, no. 5, May 1927, pp. 791-803, 2 figs. Composition, properties, uses and heat treatments of some of common types of chromium-nickel steels; low, medium and high chromium-nickel steels with carbon contents from 0.10-0.55 per cent; nickel-chromium heat-resisting alloys.

CHROMIUM STEEL

PROPERTIES. Chromium and Cobalt Steels (Note sur les aciers au chrome et au cobalt), F. M. Ostroga. Revue de Métallurgie, vol. 24, no. 3, Mar. 1927, pp. 135-145, 22 figs. Dilatation tests; mechanical tests; principal characteristics of chromium and cobalt high-carbon steels; they oxidize only slightly at high temperature.

COPPER

ELECTROLYTIC REFINING. Twenty-Five Years' Progress in the Electrolytic Refining of Copper, S. Skowronski. Am. Electrochem. Soc.—advance paper, no. 33, for mtg., Apr. 28-30, 1927, pp. 333-339, 1 fig. Multiple system of refining is used more generally than series system; annual production of electrolytic copper in United States has increased to five times that of 1902; Cottrell precipitators are universally used for recovery of precious metals from refinery-plant fumes; casting furnaces have capacity up to 400 tons, as compared with 100 tons in 1902; oil and powdered coal have superseded soft coal as fuel; direct leaching of copper ores with subsequent electrodeposition has become a very important factor.

ELECTROLYTIC SHEETS. The Properties of Electrolytic Copper Sheets, S. Sonoda. Am. Electrochem. Soc.—Advance Papers, Apr. 28-30, 1927, no. 20, 14 pp. Behavior of copper sheets electrolytically deposited on rotating cathode is compared with that of ordinary sheets rolled down from cast squares; physical properties of electrolytic sheets were investigated, and method of annealing and rolling developed which so affected these properties as to produce sheets in every way equal to ordinary rolled sheets; simplest procedure consisted in rolling sheets as they are taken from cathodes, and then annealing at 400 to 600 degrees Cent.

CORROSION

GAS CORROSION. Corrosion in the Gas Industry, I. Ginsberg. Am. Gas Jl., vol. 126, no. 15, Apr. 9, 1927, pp. 353-356 and 372. Division of corrosive influences; origin of impurities in water; other corrosive compounds; water-lime corrosion; classification of corrosion; prevention; atmospheric corrosion; artificial coatings; anti-corrosive pigments.

JOINTS AND CREVICES. Corrosion at Joints and Crevices, U. R. Evans. Engineering, vol. 123, no. 3193, Mar. 25, 1927, pp.

362-363. Discusses older and newer electrochemical views of corrosion; deals with question of corrosion at submerged joints, which might be initiated by contact between dissimilar metals, or setting of differential æration at joint; question of joints exposed to atmosphere.

CRYSTALS

INCLUSIONS IN CRYSTALLITES. Determination of Small Inclusions in Crystallites with the Aid of Slip Curves (Ueber den Nachweis von kleinen Einschlüssen in Kristalliten mit Hilfe der Erzeugung von Gleitlinien), G. Tammann and H. H. Meyer. Zeit. für Metallkunde, vol. 19, no. 3, Mar. 1927, p. 85, 4 figs. Presence of microscopic and submicroscopic inclusions in crystallites is shown by a curve in slip lines.

ELECTRIC FURNACES

ANNEALING AND HARDENING. The Development of Electric Annealing and Hardening Furnaces (Die Weiterentwicklung des elektrischen Glüh- und Härteofens), F. Wintermeyer. Centralblatt der Hütten und Walzwerke, vol. 31, no. 13, pp. 162-164. Describes different types of furnaces; advantages of electric heating.

CALCIUM-CARBIDE. Thermal and Material Efficiency of Modern Calcium Carbide and Ferrosilicon Furnaces (Energie- und Stoffbilanz moderner Carbid und Ferrosiliciumöfen), E. Schlumberger. Zeit. für angewandte Chemie, vol. 40, no. 5, Feb. 3, 1927, pp. 141-146, 8 figs. Data given are derived from modern 4500-kw. unit in Germany, and represent average good working; in manufacture of calcium carbide, 78 per cent of calcium used is present in finished pure carbide, 10 per cent is found as calcium oxide, and 6 per cent lost as dust and vapor. Brief translated abstract in Chem. & Industry, vol. 46, no. 13, Apr. 1, 1927, p. 217.

HIGH-FREQUENCY. High-Speed-High Frequency Inductive Heating, E. F. Northrup. Am. Electrochem. Soc.—Advance paper, no. 50, for mtg. Apr. 28-30, 1927, pp. 497-513, 5 figs. High frequency inductive heating permits of almost unlimited speed of heating of continuous conducting mass; new 300 lb. commercial alloy-melting furnace is specially designed for melting ferrous alloys; very rapid heating gives very high melting efficiency.

HIGH-FREQUENCY. Metallurgy in the High-Frequency Furnace (Zur Metallurgie des Hochfrequenzofens), F. Körber. Zeit. für angewandte Chemie, vol. 40, no. 4, Jan. 27, 1927, p. 124. Recent small-scale experiments at Kaiser Wilhelm Iron Research Institution show promise of great improvements in making electric-furnace steels (soft steel, chromium steel, low-carbon steels, etc.).

MIGUET. The Miguet Electrode and the Miguet Furnace, M. Arrouet. Am. Electrochem. Soc.—advance paper, no. 36, for mtg., Apr. 28-30, 1927, pp. 351-354, 1 fig. Author shows that when properly designed large single-phase furnaces are practical and will operate efficiently; feature of new furnace is author's improved continuous electrode of large cross-section; bottom of electrode is about 20 cm. above bath, leaving spacious zone for carrying out various reactions, such as refining and alloying.

NONFERROUS. Electric Furnaces in Non-Ferrous Metallurgy, D. F. Campbell. Foundry Trade Jl., vol. 35, no. 554, Mar. 31, 1927, pp. 282-284. Discussion of paper read before Inst. of Metals and published in no. 551, Mar. 10, 1927, pp. 209-212.

ROTATING-ARC TYPE. Rotating-Arc Furnace (Four électrique à arc tournant), G. E. Evreinoff and S. Y. Telny. Revue de Metallurgie, vol. 24, no. 2, Feb. 1927, pp. 57-63, 11 figs. Details of furnace developed by authors, employing characteristics obtained by use of exciting coil to cause rotation of arc; same principle can be applied to other types of electric furnaces including Heroult and Girod. Translated from Russian.

STEEL. American Electric Steel Expansion in the Last Twenty-Five Years, E. F. Cone. Am. Electrochem. Soc.—Advance Paper no. 35, Apr. 28-30, 1927, 4 pp. Over 500 electric steel furnaces are installed in United States today; they are not only producing very best grades of steel, but also large tonnages of cast iron, or gray iron, superior in quality to cupola product.

ELECTRIC WELDING, ARC

ADVANTAGES. Arc Welding, J. F. Lincoln. Mech. Eng., vol. 49, no. 5a, Mid-May 1927, pp. 558-560, 7 figs. Advantages of arc-welded steel parts over those of cast iron or of riveted construction; savings in cost effected by replacing iron castings with arc-welded steel parts; inconsistency of permitting arc welding in superheaters and steam piping and forbidding it in boilers, etc.

AUTOMOBILE-BODY ASSEMBLY. Electric Arc Welders Used in Willys-Knight Body Assembly Line. Automotive Industries, vol. 56, no. 15, Apr. 16, 1927, p. 595, 1 fig. Found advantageous in formation of joint between cowl sheet and stamped truss bar forming foundation of windshield frame.

MACHINES. The Cutler-Marsden Automatic Arc Welding Machines. Commonwealth Eng., vol. 14, no. 8, Mar. 1, 1927, pp. 312-315, 5 figs. Australian Invention, developed to do specific class of work on which ordinary electric hand welding had proved unsatisfactory, both by bare and coated electrode methods.

ROOFS. "Let's Go" on Structural Welding, C. J. Holslag. Welding Engr., vol. 12, no. 3, Mar. 1927, pp. 31-32, 4 figs. Roof is good starting place for developing welded structures; problems in roof welding.

EMPLOYEES, TRAINING OF

ROLLING MILLS. Train Employees for Better Jobs, B. Finney. Iron Age, vol. 119, no. 19, May 12, 1927, pp. 1357-1359. Courses in educational program of American Rolling Mill Co. cover wide range of subjects; instruction in hands of practical men.

FORGING

HOT AND COLD. British and American Practice in the Working of Hot and Cold Metals, F. W Spencer. Royal Soc. of Arts—Jl., vol. 75, no. 3879, Mar. 25, 1927, pp. 439-450 and (discussion) 450-456, 9 figs. Types of drop hammers in use in America; forging machines for preparing bars for sub-

sequent forging under drop hammer; production of forgings in metals other than steel, such as duralumin, brass, etc.; small forgings from cold material.

FORGINGS

BRASS. Brass Forgings, O. J. Berger. Brass World, vol. 23, no. 4, Apr. 1927, pp. 111-112. Reasons for their growing popularity; comparisons between forgings and castings; type of equipment needed and heating requirements.

FOUNDING

PRACTICE. Notes on Current Foundry Practice, G. C. Castle. Foundry Trade Jl., vol. 35, no. 554, Mar. 31, 1927, pp. 275-276. Cupola practice; desuphurizing cast iron; metallurgical standardization in foundry; molding and core troubles.

FURNACES, ANNEALING

DESIGN. Heat Treating Furnaces, C. Longenecker. Iron Trade Rev., vol. 80, no. 17, Apr. 28, 1927, pp. 1079-1081, 3 figs. Continuous furnace popular; annealing malleable castings.

HEAT TRANSMISSION IN. Heat Transmission in Annealing Furnaces with Firebrick Muffles (Die Wärmeübertragung in Glühofen mit Schamottemuffel), H. Repky. Archiv für Wärmewirtschaft, vol. 8, no. 4, Apr. 1927, pp. 101-105, 8 figs. Determination of coefficient of heat transmission of a firebrick muffle wall taking radiation into consideration; calculation of time required for annealing charge and hourly annealing rate of muffle furnace.

FURNACES, GAS

COMBUSTION TEMPERATURE. Combustion Temperature and Effective Heat in Gas-Heating Furnace (Verbrennungstemperature und Nutzwärmen in gasgeheizten Ofen, ein Beitrag zur Bewertung der Industriegase), E. Diepschlag. Feuerungstechnik, vol. 15, no. 9, Feb. 1, 1927, pp. 97-101. Contribution to utilization of industrial gases; calculation of combustion temperatures and effective heat of gas-heated annealing and melting furnace.

FURNACES, HEATING

SUSPENDED ROOFS. "Karrena" Suspended Furnace Roof. Iron & Coal Trades Rev., vol. 114, no. 3082, Mar. 25, 1927, p. 488, 2 figs. System of suspended roofs introduced by A. B. Cleworth & Co., London, which are claimed to possess greater durability than segmental arches; principle consists of especially shaped suspended blocks supported between hollow girders in direction transverse or parallel to furnace.

FURNACES, INDUSTRIAL

OIL-FIRED RIVET. An Oil-Fired Rivet Furnace. Shipbldg. & Shipg. Rec., vol. 29, no. 17, Apr. 28, 1927, pp. 496 and 498, 1 fig. Simple type of furnace which can be constructed in any shipyard.

RECUPERATORS. Recuperators for Industrial Furnaces, W. Trinks. Engrs.' Soc. of West. Pa.—Proc., vol. 42, no. 10, Jan. 1927, pp. 465-490, 16 figs., and (discussion) pp. 491-509. Discusses two cardinal questions: (1) Does it pay to use recuperators? (2) Can recuperators be built so that they are cheap, simple and durable? Types of recuperators; advantage of stack type.

STRUCTURAL ELEMENTS. Notes on the Structural Elements of Industrial Furnaces, A. E. Perkins. Mech. World, vol. 81, no. 2097, Mar. 11, 1927, p. 173. Shows how few simple calculations can enable anyone to provide adequate strength to meet forces that are at work in all industrial furnaces.

FURNACES, MELTING

CRUCIBLE STEEL. Practical Crucible Steel Melting, J. F. Kayser. Iron & Coal Trades Rev., vol. 114, nos. 3080 and 3081, Mar. 11 and 18, 1927, pp. 396-397 and 396-397, 1 fig. Deals with coke fired and producer-gas crucible-steel furnaces; runners are divided into two categories: (1) defects in pot when it leaves pot house; (2) defects developed in furnace; causes of runners; crucible-steel ingots. See also Foundry Trade Jl., vol. 35, nos. 553 and 554, Mar. 24 and 31, 1927, pp. 253-255 and 268-270.

REBABBITTING. Johnson No. 2-C Melting Furnace. Am. Mach., vol. 66, no. 16, Apr. 21, 1927, p. 674. For use in rebabbitting connecting rods; consists of three melting pots, heavily constructed of cast iron with suitable lids; any soft metal, such as lead, babbitt, tin, zinc or type metal, can be melted in them.

HARDNESS

TESTING. Hardness Testing of Steel Balls by Magnetic Methods, S. R. Williams. Am. Soc. for Steel Treating—Trans., vol. 11, no. 5, May 1927, pp. 677-690 and 823, 7 figs. In former paper published in same journal a magnetic method for testing hardness of steel balls was described; present paper deals with improvements in that method and better technique in manipulation as now worked out for outfit.

IRON

CARBON MONOXIDE, ACTION OF. Action of Pure Carbon Monoxide upon Iron at Elevated Temperatures, W. P. Fishel and J. F. Wooddell. Am. Soc. for Steel Treating—Trans., vol. 11, no. 5, May 1927, pp. 730-740, 9 figs. Study of action of pure CO upon commercially pure iron in order to show mechanism of reaction and to investigate ability of CO to penetrate iron.

CORROSION. Cause and Prevention of Iron Rust, A. J. Christopher. Power, vol. 65, no. 16, Apr. 19, 1927, p. 586. Iron will not rust in pure dry oxygen, nor in presence of air or water if they do not contain CO_2 and same water remains in contact with metal continuously; oxygen combined with other elements hastens the rusting process; moisture, CO_2 and gaseous sulphur compounds produced by burning of soft coal contribute to corrosion of iron.

DILATOMETRIC AND MAGNETIC INVESTIGATION. Dilatometric and Magnetic Investigation of Pure Iron and Iron-Carbon Alloys (Dilatometrische und magnetische Untersuchungen an reinem Eisen und Eisen-Kohlenstoff-Legierungen), H. Esser. Stahl u. Eisen, vol. 47, no. 9, Mar. 24, 1927, pp. 337-344, 24 figs. Discussion of allotropy

of pure iron differential-dilatometric investigation of electrolytic iron; true expansion of pure iron and of iron-carbon-alloys; magnetic investigation of pure iron and iron-carbon alloys.

FATIGUE FAILURE. Observations on the Microstructure of the Path of Fatigue Failure in a Specimen of Armco Iron, F. F. Lucas. Am. Soc. for Steel Treating—Trans., vol. 11, no. 4, Apr. 1927, pp. 531-540, 33 figs. and (discussion) 540-550, 15 figs. Cooperative study of microstructure of path of fatigue failure conducted under auspices of National Research Council; paths of fatigue failures in specimens of Armco iron are shown; nonmetallic inclusions act as "stepping stones" for crack; inclusions seem to influence origin and trend of crack; grain boundaries do not appear to be potential source of weakness.

SPECIFIC HEAT. Specific Heat of Iron (Die spezifische Wärme des Eisens), P. Oberhoffer and W. Grosse. Stahl u. Eisen, vol. 47, no. 14, Apr. 7, 1927, pp. 576-582, 10 figs. Heat content and allotropic change; the determined Q-t curve of pure iron is discussed in relation to modification problems of iron and compared with Q-t curves of ferromagnetic bodies, cobalt and nickel; comparison of new experiments with results obtained by Pionchon, Oberhoffer and Durrer; true content and fusion heat of transformer iron containing 4 per cent silicon.

IRON ALLOYS

GRAPHITIZATION. Notes on the A. Stable Transformation, H. A. Schwartz. Am. Soc. for Steel Treating—Trans., vol. 11, no. 5, May 1927, pp. 767-771 and (discussion) 771-780, 1 fig. Observed facts and conclusions, that A_3 stable is distinctly below A_3 metastable, and in author's judgment, adequately supported by evidence; suggestion that A_3 stable approaches A_2 in pure iron-carbon alloys, as concentration of element promoting graphitization decreases, is put forward as speculative only, although it seems to follow logically from experimental work; such conclusion would have bearing on characteristics of solid solutions.

IRON-CARBON. Graphitizing Behavior of Iron Carbide in Pure Iron-Carbon Alloys in the Critical Range, H. P. Evans and A. Hayes. Am. Soc. Steel Treating—Trans., vol. 11, no. 5, May 1927, pp. 691-706 and (discussion) 707-710, 18 figs. Theoretical treatment of action of CO—CO_2 mixtures in catalyzing graphitization of iron carbide in iron-carbon alloys; experimental proof that iron carbide of rather high purity and containing about 2.30 per cent carbon is metastable at temperatures below 1292 degrees Fahr. and above 1562 degrees Fahr. in presence of this gas mixture when it is applied at pressure of 5 atmospheres.

IRON AND STEEL

GASES IN. The Determination of Gases in Iron and Steel. Foundry Trade Jl., vol. 35, no. 555, Apr. 7, 1927, p. 304. For determination of gases in iron and steel there are used two methods; physical vacuum extraction and chemical dissolution; in former case metal is heated in vacuum and liberated gases are sucked off; in second method iron is dissolved in vacuum in the cold. Translated from Stahl u. Eisen, Sept. 10-23, Oct. 7, 1926.

IRON CASTINGS

PHYSICAL VS. CHEMICAL ANALYSIS. Mechanical Methods Make or Mar Castings, E. G. Brock. Can. Foundryman, vol. 18, no. 4, Apr. 1927, pp. 14-15. While chemical analysis is of great value in producing castings free from shrinkage and hard spots, many foundrymen accomplish, without its aid, results which others, by shrewd manipulation of elements, fail to achieve; hard castings; shrinkage and risers.

WARPING. Prevent Castings from Warping. Foundry, vol. 55, no. 8, Apr. 15, 1927, p. 297. Theories and remedies for cause and cure of warped castings.

LABORATORIES

ALLOY-CASTING RESEARCH. Research Promotes Alloy Demand. Iron Age, vol. 119, no. 15, Apr. 14, 1927, pp. 1065-1066, 2 figs. Research work going on in Michigan City at laboratory of Chrobaltic Tool Co. is directed toward widening field for use of alloy castings, particularly where they may be substituted for forgings; at present time production is confined to special and heat-resisting alloys and electrical resistance grids.

METAL RESEARCH. How Research Work Is Paying Our Industries, W. B. Lashar. Iron Trade Rev., vol. 80, no. 16, Apr. 21, 1927, pp. 1015-1018, 6 figs. Layout and equipment research laboratory at Bridgeport, Conn., built by American Chain Company; staff has recently given much attention to research in welding wire, metallic protective coatings and magnetic test methods.

LADLES

TRANSPORTERS. Electro-Hydraulic Ladle Transporter. Engineering, vol. 123, no. 3195, pp. 412-414, 18 figs. Type of transporter or pouring crane, possesses feature of value in ingot casting in steel works; mechanism is self-contained one running on rails on floor of foundry and commands large area of molten metal being carried directly on horizontal jib; machine, constructed by Belgium firm at Charleroi, is electrically and hydraulically operated.

LEAD ALLOYS

LEAD-LITHIUM. Binary Alloys of Lead and Lithium containing up to 2.2 per cent Li (Die Zweistoff-Legierungen des Bleies mit Lithium bis zu 2.2% Li), J. Czochralske and E. Rassow. Zeit. für Metallkunde, vol. 19, no. 3, Mar. 1927, pp. 111-112, 9 figs. System lead-lithium up to 2.2 lithium consists of lead mixed crystals and compound which seems to correspond with formula, Pb_3Li_2; both form eutectoid whose concentration is at 0.65 per cent lithium.

MALLEABLE CASTINGS

MANUFACTURE. Some Experiences with Malleable Cast Iron, H. Field. Foundry Trade Jl., vol. 35, nos. 553, 554 and 555, Mar. 24, 31 and Apr. 7, 1927, pp. 249-252, 271-274 and 291-292, including discussion, 22 figs. Mar. 24: Notes on number of interesting points which have arisen from time to time; as far as possible, practice

rather than theory is dealt with; melting conditions; size limitations; jolt filling of annealed cans; types of ore used. Mar. 31: Annealing pots; nickel chrome cans; specifications. Apr. 7: Conclusion and discussion.

MANGANESE

LOSSES IN BASIC SLAGS. Manganese Lost in Basic Slags, C. H. Herty, Jr. Iron Age, vol. 119, no. 15, Apr. 14, 1927, pp. 1063-1064. Nearly 280,000 tons of metal wasted in past year from open-hearth slags; how calculation is made; recovery advocated.

NONFERROUS ALLOYS. Manganese in Nonferrous Alloys, M. G. Corson. Am. Inst. Min. & Met. Engrs.—Trans., no. 1655-C-E, May 1927, 20 pp., 19 figs. Systematic description of properties and uses of alloys other than manganese bronze, manganin and duralumin; properties of manganese; binary series copper-manganese; ternary copper alloys containing manganese.

STEEL INDUSTRY. The Importance of Manganese in the Steel Industry, H. M. Boylston. Am. Inst. Min. & Met. Engrs.—Trans., no. 1560-C, May 1927, 6 pp. Manganese as alloying element; economic importance of manganese in steel making; situation in United States in 1926.

METALLOGRAPHY

STEEL FOUNDRIES. Metallography in the Steel Foundry. Research Group News, vol. 4, no. 1, Apr. 19, 1927, pp. 122-127, 8 figs. Microscopic examination; components of steel; granular structure of steel; metallography in group plants.

METALS

CORROSION. Corrosion (Reichsausschuss für Metallschutz). Zeit. für angewandte Chemie, vol. 40, no. 3, Jan. 20, 1927, pp. 96-103. Symposium of papers at 1926 meeting of Reichsausschuss für Metallschutz, as follows: Corrosion Research in England, M. Haas; Rust Damage and Protection Costs, W. Widderholt; Stainless Steels, Strauss; Estimating Rate of Rusting and Rusting Tendency, Especially of CR Steels, Duffek; Aluminum Corrosion, E. Maas; Nomenclature of Tars and Bitumens, Mallisson; Waters Which Attack Metals and Cement, Klut; Corrosion and Practical Boiler Operation, A. Splittgerber; Colloid Chemistry and Corrosion Research, Beck; Theory of Surface Coatings, A. Blom; Storch-Morawski Reaction, H. Wolff; Corrosion Protection by Coatings, O. Jüger; Standardization, K. Wuerth; Chemical Behavior and Overvoltage of Metals, F. Liebreich; Cable Corrosion, O. Haehnel; Light Aircraft Alloy Corrosion, Rackwitz.

CORROSION FATIGUE. Stress-Strain-Cycle Relationship and Corrosion-Fatigue of Metals, D. J. McAdam, Jr. Am. Soc. for Testing Matls.—Proc., vol. 26, part 2, 1926, 40 pp., 12 figs. Material and methods of investigation; following subjects are considered: stress-cycle graph extended to nominal stresses well above tensile strength of material and over range from less than 1000 to more than 100,000,000 cycles; interrelationship between stress-cycle, stress-deflection and deflection-cycle graphs; effect of cyclic repetition on deflection and hysteresis; stress-cycle graph as affected by cycle frequency, thermal conductivity of specimen and environment, and form of specimen; extrapolation of stress-cycle graphs; evidence is presented that very slight corrosion when simultaneous with fatigue causes low resistance to fatigue; damaging effect is greater the harder the steel; advantage of heat treatment may thus be practically neutralized; ratios of "corrosion-fatigue" limits to endurance limit are compared with other physical properties of steel; practical importance of corrosion fatigue for ferrous and nonferrous metals.

COLD WORKING. Influence of Cold Working on Speed of Evaporation (Ueber die Beeinflussung der Verdampfungsgeschwindigkeit durch Kaltbearbeitung mit einer Notiz über die Schmelz- und Umwandlungspunkte kaltbearbeiteter Metalle). F. Sauerwald, H. Patalong and H. Rathke. Zeit. für Physik, vol. 41, no. 4-5, Feb. 14, 1927, pp. 355-377, 1 fig. Contains note on fusion and transformation points of cold-worked metals; kinetic theory of cold working and recrystallization.

CREEP. Some Observations on the Creep of Metals, D. Hanson. Metallurgist (Supp. to Engineer), Apr. 20, 1927, pp. 54-56. Refers to paper by R. W. Bailey read before Inst. of Metals in March 1926, on mechanism of creep; preliminary results of present author's research into creep of metals, carried out with view to ascertaining effect of creep on properties of material; material selected was pure aluminum sheet; most important observation is considerable degree of strain hardening which occurred in method during process of creep.

DAMPING PROPERTIES. Damping Properties of Certain Metals Under Influence of Torsional Vibration (Die Dämpfungseigenschaften von einigen Metallen bei Drehschwingungen), Dr. O. Feubner and E. Ramb. Zeit. für Metallkunde, vol. 19, no. 3, Mar. 1927, pp. 115-116, 6 figs. Deals with problems of damping properties of metals, which provide a guide for determining resistance of material to repeated stress; tests were carried out on copper, aluminum and iron.

GASES IN. Gases in Metals. Metallurgist (Supp. to Engineer), Apr. 20, 1927, pp. 50-51. Review of recent investigations, with special reference to hydrogen, which is principal gas present in most metals; modern work indicates that it is most readily absorbed the higher the temperature of a metal is raised above its melting point and gas is only slowly eliminated during subsequent cooling down to freezing range; special action is required to bring about separation or evolution of gas; slow solidification is perhaps most perfect method.

GRAIN GROWTH. Relation of Surface to Volume in Crystals as a Determining Factor in Grain Growth of Metals, G. W. Walker. Am. Soc. for Steel Treating—Trans., vol. 11, no. 4, Apr. 1927, pp. 619-625. Attempt is made to obtain more critical view of mechanism involved in grain growth of metals taking into consideration physical factors; surface, volume, surface tension, surface energy, solubility, boundary migration, etc.; also attempt is made to consider these phenomena in quantitative aspect as far as data is available.

IDENTIFYING TESTS. Simple Tests for Identifying Metals. Oxy-Acetlyene Tips, vol. 5, no. 9, Apr. 1927, pp. 174-178, 11 figs. Discusses non-technical shop methods for determining nature of materials; tests include appearance, fracture, grinding-wheel tests and behavior under blowpipe; deals with gray cast iron, malleable iron, cast steel, steel forgings, mild or low-carbon steel, high-carbon steel, alloy steels, aluminum, copper, brasses and bronzes, etc.

RECRYSTALLIZATION. Investigations of Recrystallization Phenomenon in Silver, Copper and Aluminum (Untersuchungen über den Rekristallisationsvorgang bei Silber, Kupfer und Aluminium), R. Glocker and H. Windmann. Zeit. für Metallkunde, vol. 19, no. 2, Feb. 1927, pp. 41-43, 7 figs. Describes three types of crystallite formation in recrystallization of rolled sheets; effect of heat treatment preceding cold rolling; effect of intermediate annealing; points out great influence of very small impurities on recrystallization of silver.

STRAIN HARDENING. Strain Hardness of Metal Materials under Tensile and Pressure Tests (Die Verfestigung metallischer Werkstoffe beim Zug- und Druckversuch), F. Körber and H. Müller. Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf, vol. 8, no. 12, 1926, pp. 179-199, 32 figs. Tests to determine strain hardness through tensile tests on metals, ingot steel and mixed-crystal alloys; determination of strain hardness by compression tests on lead, aluminum, copper. Bibliography.

SUPERHEATED STEAM, EFFECT OF. Why Metals Fail Under Influence of Steam Once Superheated, B. Houghton and D. C. Weeks. Power, vol. 65, no. 15, Apr. 12, 1927, pp. 540-542, 7 figs. Presents deductions on cause of metal failures from observations extending over a period of thirty years of power-plant practice combined with recent observations of nature of superheated steam as produced in modern power plants.

MOLDS

WATER-COOLED. Water-Cooled Molds. Metallurgist (Supp. to Engineer), Apr. 20, 1927, pp. 56-58, 5 figs. Two important factors influencing the quality of ingots are behavior of mold and process of solidification; refers to work by Junker in Zeit. für Metallkunde, Oct. 1926, with special reference to brass casting; important field of application for water-cooled mold lies in casting of large aluminum-alloy ingots.

NICKEL

USES. Practical Uses of Pure Nickel, R. J. McKay. Am. Electrochem. Soc.—Advance paper, no. 47, for mtg., Apr. 28-30, 1927, pp. 457-461. Chemically pure nickel does not show any marked differences in properties from present grades of high purity; applications of very pure commercial nickel; sulphur-free nickel is now commercial product.

NICKEL ALLOYS

CHROMIUM-NICKEL. Comparative Tests on Chrome-Nickel Wires (Vergleichende Untersuchungen über die Oxydation von Chromnickellegierungen bei hohen Temperaturen), W. Rohn. Elektrotechnische Zeit., vol. 48, nos. 8 and 10, Feb. 24 and Mar. 10, 1927, pp. 227-230 and 317-320, 6 figs. New method explained for comparative testing of alloy wires such as are used for units in electric heating devices; according to this method suitability of such alloy wires is indicated directly by amount of oxidization which takes place at repeated heatings of conductor; very large number of tests were made with German, English and American alloys, consisting of chromium, nickel, iron and molybdenum; data obtained are compiled in 34 curve sheets.

NICKEL-COPPER. Nickel-Copper Alloys in Modern Engineering, W. T. Griffiths. Engineering, vol. 23, no. 3197, Apr. 22, 1927, pp. 475-477, 3 figs. Account of present state of knowledge of alloys containing less than 50 per cent nickel; molding and casting; mechanical and heat treatment; effect of annealing upon mechanical properties; mechanical properties at elevated temperatures; electrical and anti-corrosion properties; uses.

PERMALLOY. Space Lattice of "Permalloy" (Das Raumgitter von Permalloy), R. Forster. Physikalische Zeit., vol. 27, no. 24, Dec. 15, 1926, pp. 829-830, 1 fig. Lattice constant increases with increasing iron content; McKeehan's result confirms additivity of lattice constant; lattice is independent of magnetic properties.

NICKEL STEEL

INSTABILITY. The Cause of Instability of Nickel Steel (La cause de l'instabilité des aciers au nickel), C. E. Guillaume. Archives des Sciences Physiques et Naturelles, vol. 9, no. 5, Jan.-Feb. 1927, pp. 5-15, 5 figs. Criterion of instability; action of carbon, manganese, copper and chromium; shows that in order to stabilize nickel steel it is necessary to hinder the formation of cementite by combining carbon with a substance for which it has a stronger affinity than for iron, such as tungsten and vanadium.

LOCOMOTIVE-BOILER SHELLS. Locomotive Boilers with Nickel Steel Shells. Ry. Mech. Engr., vol. 101, no. 4, Apr. 1927, pp. 196-200, 9 figs. Permits 25 per cent increase in pressure on Canadian Pacific's new 4-6-2 and 4-8-2 types.

NONFERROUS METALS

ANNEALING. A Critical Discussion of the Various Methods of Annealing Nonferrous Metals, J. Frith. Brit. Nonferrous Metals Research Assn.—Bul., no. 18, Jan. 1927, pp. 7-12. With view to deciding which to use in any particular case.

CORROSION. The Atmospheric Corrosion of Metals. Engineer, vol. 143, no. 3717, Apr. 8, 1927, pp. 374-376. Review of second experimental report to Atmospheric Corrosion Research Committee of Brit. Nonferrous Metals Research Assn.; deals with indoor and open-air exposure tests, former including associated laboratory experiments.

HARDNESS AND TENSILE STRENGTH. Hardness and Tensile Strength (Härte und Zugfestigkeit), R. Baumann. Zeit. für Metallkunde, vol. 19, no. 2, Feb. 1927, pp. 71-72, 3 figs. Conversion of ball-pressure hardness into tensile strength for a number of nonferrous metals.

MOLTEN SOLDER, ATTACK OF. The Attack of Molten Metals on Certain Nonferrous Metals and Alloys, H. J. Hartley. Engineering, vol. 123, no. 3194, Apr. 1, 1927, pp. 399-403, 16 figs. Metallographic examination of unstressed brasses attacked by molten tin at 300 degrees Cent.; tensile tests on materials under tin and solder attack; experiments on copper and brass wire; concludes that tin content of solder seems of greatest importance in determining its attacking power. Paper read before Inst. of Metals.

SEGREGATION. The Mechanism of Inverse Segregation in Alloys, R. Genders. Engineering, vol. 123, no. 3193, Mar. 25, 1927, pp. 370-372 and 405-406, 14 figs. Deals chiefly with nonferrous alloys which are usually cast in molds smaller than those used for steel and which solidify with relatively great rapidity; common type of heterogeneity is segregation outwards of lower melting constituent of alloy, in contradiction of result which would be predicted by equilibrium diagram; phenomenon has been termed inverse segregation or liquation; reviews present theories and suggests directions in which data essential for completion of general theory might be sought. Paper read before Inst. of Metals.

OPEN-HEARTH FURNACES

BASIC PRACTICE. Basic Open-Hearth Practice, C. H. Herty, Jr. Am. Soc. for Steel Treating—Trans., vol. 11, no. 4, Apr. 1927, pp. 569-582. Open-hearth practice for three types of charges are compared, three heats of steel being used for comparison; first two are pig iron and scrap heats with no ore in charge, first of these charged with very large scrap, second with medium scrap; third heat is iron ore heat, 20,000 lbs. of ore being charged with scrap; comparison covers melting period, lime boil, working period and efficiency of deoxidizers used; effect of sulphur in gas on sulphur content of metal.

100-TON. The design of 100-Ton Open-Hearth Furnaces (Dimensions des fours Martin de 100 tonnes), A. Pavloff. Revue de Métallurgie, vol. 24, no. 1, Jan. 1927, pp. 1-9. Results of author's investigations and calculations; dimensioning of hearth surface; gas and air burners; recuperators; valve flues and stack. Translated from Russian.

RECUPERATORS. Recuperators Applied to Open-Hearth Furnaces, W. H. Fitch. Engrs.' Soc. West. Pa.—Proc., vol. 42, no. 10, Jan. 1927, pp. 506-517 and (discussion) 517-530, 7 figs. Use of recuperator, in combination with regenerators; use of screen or checker chamber before recuperator is desirable for purpose of removing oxide and dust; corebusters are employed to compel air to pass in contact with wall of tube; they consist of solid cylinders made of fireclay; how construction of recuperator influences results as to uniformity of temperature of combustion air leaving recuperator; in applying principle of author's design of recuperator to open-hearth furnace for manufacture of steel, only limitation appears to be quantity, temperature, and nature of dust that may be deposited on tubes.

REFRACTORIES. Factors Affecting Open Hearth Refractories, B. M. Larsen and A. Grodner. Blast Furnace & Steel Plant, vol. 15, no. 4, Apr. 1927, pp. 161-164, 10 figs. Certain relations between refractories service, insulation, and flow of heat in open-hearth furnace; investigation conducted under operating conditions.

SILICA BRICK IN. The Alteration of Silica Bricks in Open-Hearth Furnaces, E. Sieurin. Ceramic Soc.—Trans., vol. 25, part 4, 1925-1926, pp. 400-406. In order to obtain direct comparison under works conditions, sample bricks were built into one of side walls of open-hearth furnace hearth at Swedish steel mill; these bricks were particularly well burnt; at same time bricks, also of superior quality, of German manufacture, were placed in walls of same furnace hearth; tests made at Höganäs on above bricks; although softening point of bricks is about same as that of standard silica brick, resistance to corrosion by slag decreases owing to admixture of considerable quantity of ferric oxide.

STEEL FURNACE-BANK CRYSTALS. Steel Furnace Crystals, J. S. C. Primrose. Am. Soc. Steel Treating—Trans., vol. 11, no. 5, May 1927, pp. 763-766, 5 figs. From description of steel-furnace-bank crystal group, and micrographs of section taken from 50-lb. specimen, striking features arising from slow cooling of hyper-eutectoid steel are discussed with reference to brittle Widmanstätten structure; very low power resolution of pearlite lamellæ; and intersection of primary cementite needles are noteworthy.

TECHNICAL PROBLEMS. Open-Hearth Operators Talk Shop. Iron Age, vol. 119, no. 19, May 12, 1927, pp. 1369-1373, 4 figs. Review of discussions held at meeting of open-hearth conference, under auspices of American Inst. of Min. & Met. Engrs.; sloping backwalls; relation of areas of furnace hearth, ports, flues, checker chambers and stack; ports for gas, oil and producer-gas furnaces; waste-heat boilers; effect of mold dimension on blowhole locations in rimming steel; European and American open-hearth practice; turbo-blowers for gas house.

WASTE-HEAT BOILERS. Results of Tests on Waste Heat Boilers, M. Ebner and M. Hayes. Blast Furnace & Steel Plant, vol. 15, no. 4, Apr. 1927, pp. 191-192, 1 fig. Installation of boilers on three 90-ton open-hearth furnaces; after service of 9 mos. operation is checked.

OXYACETYLENE WELDING

LOCOMOTIVE SIDE RODS. Cutting Side Rods with Acetylene Torch, F. H. Williams. Can. Machy., vol. 18, no. 16, Apr. 21, 1927, pp. 22-23, 7 figs. Shows results, good and bad, of cutting steel side rods of locomotives by this method, such rods being medium steel forgings, with carbon running from .25 to .55 per cent, but not higher carbon or alloy steels.

PLATE. Welding Plate of Medium Thickness. Acetylene Jl., vol. 28, no. 11, May 1927, pp. 521-524, 9 figs. Exercises suggested for training new welders in fundamental principles of welding materials used in fabrication of thin-walled tanks extracted from book by R. Granjon, P. Rosenberg and A. Desgranges, of Paris.

STEEL CASTINGS. How Steel Castings are Oxwelded. Oxy-Acetylene Tips, vol. 5, no. 9, Apr. 1927, pp. 164-165, 1 fig. Preparation for welding; preheating is usually necessary; welding technique; annealing.

STORAGE TANKS. Oxyacetylene-Welded Construction of a Large High-Pressure Storage Tank, H. E. Rockefeller. Mech. Eng., vol. 49, no. 5, May 1927, pp. 405-411, 20 figs. Design of tank; selection of material; checking of welders; welding longitudinal and girth seams; design of new manhole reinforcing ring and its welding to manhead.

TORCH MANIPULATION. Proper Use of Welding Torch, E. Louden. Brass World, vol. 23, no. 4, Apr. 1927, pp. 113-114, 4 figs. Hints about its manipulation and care; preheating for welding brass, aluminum and sheet metal; qualifications of welder.

PIPE, CAST-IRON

GAS MAINS. Metals Used in Gas-Works Practice, R. Fife. Gas Jl., vol. 177, no. 3332, Mar. 30, 1927, p. 814. Author prefers cast-iron pipes cast in green sand to those cast in dry sand, for former are better able to withstand corrosion; addition of copper to cast iron greatly enhances its corrosion-resisting properties.

PYROMETERS

FOUNDRY APPLICATIONS. Pyrometer Aids Good Casting Return, R. D. Bean. Foundry, vol. 55, no. 9, May 1, 1927, pp. 347-348. Selecting proper equipment; types of thermocouples; typical application.

RAILS

FLAW DETECTION. Detecting Hidden Flaws in Rails. Iron Age, vol. 119, no. 15, Apr. 14, 1927, p. 1059. Magnetizing device, developed in Japan, claimed capable of locating flaws, fissures, segregation and other defects in rolled sections.

JOINTS, WELDED. Aluminum Thermit Welding of Rail Joints on the Berlin Rapid Transit (Aluminothermische Schienenschweissung bei den Stadt-Schnellbahnen [Untergrundbahnen]), H. Lotze. Verkehrstechnik, vol. 40, no. 9, Mar. 4, 1927, pp. 138-139. Outline of extent and conditions of aluminum thermit joint welding on Berlin subway; advantages obtained, and difficulties overcome.

JOINTS, WELDED. Committee on Welded Rail Joints—Progress Report No. 5—July 1926. Am. Welding Soc.—Jl., vol. 6, no. 3, Mar. 1927, pp. 12-72, 38 figs. Summary of tests and reports; shear tests. Report on Longitudinal Shearing Tests of Rail Plate Welds, R. J. Fogg; analysis of results of shear tests giving highest values; Comments on Shear Test Results, H. L. Whittemore; telemeter investigations; report on preliminary tests of welded rails, Baltimore, Aug. 2-3, 1926; program of additional investigations proposed by Committee; suggested program for strain gage measurements of welded rail joints.

ROLLING. History of the Rolling of Rails, G. T. Raidabaugh. Blast Furnace & Steel Plant, vol. 15, no. 4, Apr. 1927, pp. 183-185 and 197, 8 figs. Review of development of rail sections from year 1857 to 1910; during this period weight increased from 50 to 135 lbs. Reprinted by courtesy of Bethlehem Steel Co.

REFRACTORIES

METAL FURNACES. Refractory Materials for Metal Furnaces, W. J. May. Mech. World, vol. 81, no. 2101, Apr. 8, 1927, p. 253. For crucible and other furnaces melting up to, and including, cast iron, good fireclay bricks with fireclay jointing will be found sufficiently refractory and durable, as a heat of less than 2500 degrees Fahr. is needed, but over this it is desirable to have something better.

SLAG-CORROSION RESISTANCE. The Testing of Refractory Materials for Resistance to Slag Corrosion and Erosion, A. J. Dale. Ceramic Soc.—Trans., vol. 25, part 4, 1925-1926, pp. 326-338. Previous investigations on resistance of different refractories to slagging effects; methods involving measure of penetration; estimate of change in ultimate chemical composition of brick or of slag after reciprocal interaction.

STEEL-FURNACE. Corrosion of Steel Furnace Refractories, A. Scott. Ceramic Soc.—Trans., vol. 25, part 4, 1925-1926, pp. 339-351, 2 figs. Describes normal types of corrosion.

ROLLING MILLS

D. C. MOTORS FOR. The Application of Direct Current Motors to Main Roll Drives, H. A. Winne. Iron & Steel Engr., vol. 4, no. 4, Apr. 1927, pp. 194-202, 10 figs. Geared vs. direct connected drives; flywheels; ventilation; methods of speed adjustment; mill-type motor construction; control and switchboard; magnetic-control equipment; continuous mill with individually driven stands is responsible for notable increase in use of d. c. motors for mail roll drives.

ELECTRIC DRIVE. 1926 Developments in Electric Drive, A. F. Kenyon. Iron Age, vol. 119, no. 15, Apr. 14, 1927, pp. 1068-1071, 5 figs. Rolling-mill equipment underwent notable advances in control; large units multiplying rapidly.

ELECTRIFICATION. Electrification of Sheet Mills, J. S. Murray. Iron & Steel Engr., vol. 4, no. 4, Apr. 1927, pp. 173-193, 38 figs. Details of Toronto Works of Follansbee Brothers Co. engaged in manufacture of "Follansbee Forge" full finished sheets, in gages ranging from 10 to 24, and in sizes up to maximum of 48 in. wide and 144 in. long; details of power plant; bar-mill reversing equipment; open-hearth department; ingot furnaces and bar mill; powdered-coal plant; departmental organization.

MERCHANT. The Rolling of Commercial Iron and Small Sections (Le laminage des fers marchands et des petits profiles), E. Poncelet. Revue de Métallurgie, vol. 24, no. 3, Mar. 1927, pp. 109-123, 26 figs. Describes methods and equipment employed; shearing machines, cooling beds, etc., rolling of T-iron, angle, channel, flat and round iron, etc.

ROD AND WIRE. New Features are Incorporated in Tidewater Rod and Wire Mill, G. A. Richardson. Iron Trade Rev., vol. 80, no. 18, May 5, 1927, pp. 1151-1154, 6 figs. New mill placed in operation at

Sparrows Point, Md., division of Bethlehem Steel Co.; rod mill is entirely gear-driven.

STEEL INGOTS. Rolls Steel Ingot Weighing 63,000 Lbs. Iron Age, vol. 119, no. 19, May 12, 1927, pp. 1376-1377, 2 figs. Slabs 130 in. wide and 3¼ in. thick, for fabrication into gear-reduction unit flywheels, produced on 206-in. plate mill.

ROLLS

PINCHING. Pinching of Rolls (Walzenschärfen), H. Cramer. Stahl u. Eisen, vol. 47, no. 14, Apr. 7, 1927, pp. 582-586, 10 figs. Increasing rolling efficiency by pinching of rolls; pinching designs; relation between speed of rolls and overrolling.

SHEET METAL

ANNEALING. New System Flat-Pack Sheet-Annealing Process. Iron & Coal Trades Rev., vol. 114, no. 3085, Apr. 15, 1927, p. 606, 3 figs. It is claimed that with this system difficulties are eliminated, while it is possible with flat pack, under satisfactory conditions of efficiency and minimum handling costs, to obtain heating surface as high as 30 sq. ft. per ton of sheets; main advantages claimed for system are summarized.

PRODUCTION WELDING. Production Welding of Sheet Metal. Acetylene Jl., vol. 28, no. 11, May 1927, pp. 519-520 and 524, 4 figs. Growing use of sheet steel for permanence of service is accompanied by large fabrication economies through welding.

ROLLING. Recent Developments in the Rolling of Sheet Steel. Mech. Engr., vol. 49, no. 5, May 1927, pp. 451-454, 2 figs. Particulars regarding process of rolling steel sheets; application of continuous principle to sheet rolling, and increased production and savings possible through its adoption.

SILICON STEEL

STRUCTURAL. Structural Silicon Steel Has Special Properties, J. Meiser. Iron Age, vol. 119, no. 16, Apr. 21, 1927, p. 1146. Results of German open-hearth heats; details of composition and physical tests; Bosshart and regular heats compared. Translated from Stahl u. Eisen, Mar. 17, 1927.

SILVER

ALLOYS. New Silver Alloys (Neue Silberlegierungen), W. Guertier. Zeit. für Metallkunde, vol. 19, no. 2, Feb. 1927, pp. 68-70, 4 figs. Results of investigations of behavior of alloying metals other than copper; it was found that binary alloys with manganese, zinc, cadmium, tin, aluminum and magnesium, are more resistant to corrosive influence than silver-copper alloy.

STEAM TURBINES

BLADE EROSION. Tests on Erosion Caused by Jets, E. Honegger. Brown Boveri Rev., vol. 14, no. 4, Apr. 1927, pp. 95-104, 14 figs. Purely qualitative tests have shown that erosion increases rapidly with velocity; metals which resisted erosion at speed of 130 m. per sec. showed large holes after having been tested at 200 and 225 m. per sec.; relation between resistance to erosion of rustless steel and heat treatment; comparison between rolled 5.0% nickel steel and drawn rustless chrome steel clearly showed superiority of former; tests on cast iron of various qualities showed that this metal offered smaller resistance to erosion than steel; characteristic erosion curves; influence of size of drops.

STEEL

ABNORMAL. Theory to Explain Abnormal Steel, J. D. Gat. Iron Age, vol. 119, no. 16, Apr. 21, 1927, pp. 1142-1144, 4 figs. Presence of unusual amount of dissolved oxygen promotes non-hardenability; results of an investigation of many steels.

AGING. The Aging of Mild Steel. Metallurgist (Supp. to Engineer), Apr. 20, 1927, pp. 49-50. Definition of aging; while it is clear that recovery of wrought iron and mild steel from plastic overstrain is an intricate phenomenon of great importance, immediate question is whether it is this phenomenon which is described as aging in literature; further question arises as to what is meant by describing mild steel as free from aging.

AUSTENITE DECOMPOSITION. The Decomposition of the Austenitic Structure in Steels, R. L. Dowdell and O. E. Harder. Am. Soc. for Steel Treating—Trans., vol. 11, no. 4, Apr. 1927, pp. 583-606, 72 figs. Effect of tempering quenched steels for different periods of time at different temperatures has been studied by means of changes in hardness and changes in microstructures; attention has been given to effect of severe mechanical stress, such as upsetting austenitic steel, on its decomposition on tempering; austenite more frequently tempers to troostite, but in certain cases typical martensitic needles have been produced on tempering; temperature at which martensitic structure breaks down in any given steel is lower than temperature at which austenitic structure in same steel breaks down.

AUSTENITIC STRUCTURE. The Decomposition of the Austenitic Structure in Steels, R. L. Dowdell and O. E. Harder. Am. Soc. for Steel Treating—Trans., vol. 11, no. 5, May 1927, pp. 781-790, 14 figs. Reports series of tests which was made to determine effect of stress on stability of austenitic structures; attempt is made to distinguish between effect of compression and tensile stresses; tests on effect of bending stresses during tempering, severe upsetting at room temperature and during tempering, tensile stresses at room temperature and at temperature of carbon dioxide snow; typical martensitic needles were produced by tensile stresses in ring specimens and by subjecting specimens which had been stressed in tension to temperature of CO_2 snow; stresses were found to make austenitic structures less stable both at low and at elevated temperatures.

BALL-BEARING. Comparative Tests on Ball-Bearing Steels, T. L. Robinson. Am. Soc. for Steel Treating—Trans., vol. 11, no. 4, Apr. 1927, pp. 607-618, 23 figs. Results of series of alternating stress tests in which attempt was made to compare some alloy steels now used in ball bearing manufacture; tests are supplemented by static bending test designed to eliminate as far as possible any alignment factors; test results and subsequent microscopic examina-

tion indicated that size and distribution of particles of excess cementite were factors in performance of steel both under reversed stress or fatigue tests and under static bending test; steels in which these particles of cementite were comparatively small and uniformly distributed showed markedly greater endurance and strength.

CEMENTATION. Study of Gaseous Cementation (Contribution à l'étude des cementations gazeuses), M. Perot. Revue de Métallurgie, vol. 24, no. 1, and 2, Jan. and Feb. 1927, pp. 23-35 and 79-92, 38 figs. Cementation by cyanogen; influence of temperature on cementation; influence of time, pressure, and concentration.

COPPER DEPOSITION. Protecting Steel With a Copper Film, W. S. Barrows. Can. Foundryman, vol. 18, no. 4, Apr. 1927, pp. 15-16. Successful prevention of carburization of steel by deposition of copper upon it depends very largely on production of non-porous coating of copper, moderately thick, firm, adherent and close-grained.

PHYSICAL COMPOSITION. The Physical Composition of Steel, J. D. Gat. Blast Furnace & Steel Plant, vol. 15, no. 4, Apr. 1927, pp. 173-176, 1 fig. Open-hearth and rolling-mill practice and their influence upon grain structure; effects of rate of cooling; types of ingot molds employed.

RUSTLESS. Use of Non-Rusting Steel in Paper Making, H. W. Stel. Paper Trade Jl., vol. 84, no. 17, Apr. 28, 1927, p. 47. Up to present time use of non-rusting steels in beaters has remained an unsolved problem which has now been solved by development of "Nonoxy" steel, new departure in steel making which possesses twofold quality of being rust-resistant and of standing up very well under severe wear to which beater roll and bedplate knives are subjected. Translated from Le Papier, vol. 29, Dec. 1926.

SMOOTH-FINISH MACHINING. Smooth Finish Machining of Low Carbon Plain and Alloy Steels, J. S. Vanick and T. H. Wickenden. Am. Soc. for Steel Treating—Trans., vol. 11, no. 4, Apr. 1927, pp. 551-568, 3 figs. Plain and alloy low-carbon steels of carburizing type, have, under incorrect operating conditions, tendency to machine to rough finish in final or finishing cuts; it was found that, for each steel and its particular heat treatment, this result was due to existence of critical-range of volume-removal rates within which rough finish was obtained; by avoiding this critical range, smoothly finished surfaces could be obtained; applying results of this investigation to practice, it was found that cutting conditions leaving rough surface, could be changed to give smooth finish by: lowering, or preferably increasing cutting speed until it is outside of critical range; maintaining speed, but changing cut or feed; sharpening cutting angle of tool and maintaining speed and shape of chip; changing hardness of steel being cut.

TEMPER BRITTLENESS. Temper Brittleness of Steel (Discussion sur la fragilite de revenu). Revue de Métallurgie, vol. 24, no. 1, Jan. 1927, pp. 36-40. Discussion by A. Portevin and L. Brenet of article by L. Gillet and M. Ballay, published in same journal vol. 23, Sept. and Oct. 1926; and reply by authors. See reference to original article in Eng. Index 1926, p. 713.

STEEL CASTINGS

CHEMISTRY IN. Chemistry's Part in Making Steel Castings. Research Group News, vol. 4, no. 1, Apr. 19, 1927, pp. 115-118, 1 fig. Fundamental principles of ferrous metallurgy; functions of chemical laboratory.

HEAT TREATMENT OF. Exacting Inspection as Related to Satisfactory Performance. Research Group News, vol. 4, no. 1, Apr. 19, 1927, pp. 118-122, 5 figs. First essential for scientific heat treatment is pyrometer; welding safeguards; adequate metal in risers; metallic cement prohibited; cleaning regulations.

LOCOMOTIVE FRAME BEDS. Improved Locomotive Frame Bed. Ry. & Locomotive Engr., vol. 11, no. 4, Apr. 1927, pp. 103-105, 3 figs. Mountain-type locomotive of Southern Pacific Railway having one-piece cast-steel locomotive bed; cast steel used contains 0.18 per cent carbon and 0.73 per cent manganese; time required to pour steel into mold for one complete engine bed was about 11 minutes; steel was poured through special nozzle from ladle containing about 50 tons of molten steel.

STEEL, HEAT TREATMENT OF

GERMAN PRACTICE. The Heat Treatment of Steel (Om Värmebehandling av stal), E. Ryd. Teknisk Tidskrift (Mekanik), vol. 57, no. 15, Apr. 16, 1927, pp. 52-54. Report of Swedish engineer on German practice.

OIL-WELL SUCKER RODS. How Science is Improving Sucker Rods, H. A. Cassidy. Oil Bul., vol. 13, no. 4, Apr. 1927, pp. 393-399, 6 figs. Development of new heat-treated sucker rods of D & B Co.; information was compiled from tabulations prepared by company's engineering department and from laboratory notes and reports submitted by author in his capacity as consulting metallurgical engineer.

RAILS. New Process for Heat Treatment of Steel Rails (Nouveauz traitments thermiques de l'acier à rails), Marcotte and Martineau. Revue de Métallurgie, vol. 24, no. 1 and 2, Jan. and Feb. 1927, pp. 10-19 and 68-78, 16 figs. Details of process, invented by C. F. Sandberg, and employed in France at Hagondange works; principles of process and details of installation; shows that two processes, very different from each other, can be satisfactorily applied to prolonged life of rails: (1) sorbitic process, as applied at Hangondange, which gives rail a sorbitic texture; and (2) process in situ, applied to street car rails on track which gives superficial martensite layer which greatly increases life of rail.

ROCK-DRILL STEEL. Heat Treating Rock Drill Steel. Ariz. Min. Jl., vol. 10, no. 21, Mar. 30, 1927, pp. 17-22, 6 figs. Discusses preparation of straight carbon rock-drill steel in general, and describes in detail practice at United Verde Copper Co.; explains value and limitations of some equipment used in treating drill steel.

SHOP EQUIPMENT. Equipping Shop To Heat Treat Economically, E. F. Davis. Iron

Trade Rev., vol. 80, no. 17, Apr. 28, 1927, pp. 1073-1076 and 1081, 5 figs. Essentials of up-to-date heat-treating department from metallurgical viewpoint; pearlite is most important constituent in steel and has an important effect upon machinability; hardness of metal has nothing whatever to do with machining conditions; gears from which specimens were taken were annealed in stationary furnaces and investigation revealed impossibility of producing uniform annealing in batch furnaces.

STRESSES DUE TO QUENCHING AND TEMPERING. Stresses in Quenched and Tempered Steel, S. L. Hoyt. Am. Soc. for Steel Treating—Trans., vol. 11, no. 4, Apr. 1927, pp. 509-527 and (discussion) 528-530 and 658. When high-carbon steel is quenched from above its critical point in water, transformation takes place in steel at about 660 degrees Fahr. which is accompanied by volume change of order of 1 per cent; it has been shown by Heyn, Scott and others that mechanism of reaction of steel to quenching operation is such that internal stresses are necessarily set up; tempering is accompanied by volume changes; indicates how stresses operate during quenching and tempering to produce strains in steel and shows how, on such a basis, apparently anomalous dimensional changes may be accounted for; general argument is that tensile and compressive stresses may not, at times, exactly balance each other and that their tendency to equalize results in strains or dimensional changes which are superposed on those due to volume changes.

STEEL, HIGH-SPEED

HIGH SPEED STEELS, F. C. A. H. Lantsberry. Am. Soc. for Steel Treating—Trans., vol. 11, no. 5, May 1927, pp. 711-725 and (discussion) 725-729 and 803, 4 figs. Technique of various methods of producing high-speed steels in England, America and Germany, with special reference to methods and processes used in Sheffield, England, in making, composition, working, hardening, tempering, and theory of high-speed steels; writer is of opinion that modern tendency is to produce high-speed steels in electric furnace where refining operations make possible use of inferior raw materials and results in greater mass production, but that crucible process is favored in his works in Sheffield because of inherent quality of steel which results in more uniform product in small quantities; comparative analyses of English, American and German high-speed steels; in England high-speed steels are classified according to their tungsten content; in Germany tendency is to increase chromium content.

STEEL WORKS

ACCIDENT PREVENTION. Full Accident Prevention in Iron and Steel Works (Die Unfallverhütung beim Eisen- und Stahlwerk Hoesch), H. Bitter. Stahl u. Eisen, vol. 47, no. 14, Apr. 30, 1927, pp. 569-576, 13 figs. American methods; new organization in German works; psychic effect, accident pictures and posters; statistics, lectures and rules; mechanical protective devices, gas protection; maintenance and improvements; first aid; advantages of accident protection for employers and employees.

CRANES, INGOT TONGS. The Gripping Force of Ingot Tongs, W. E. Weight. Engineering, vol. 123, no. 3190, Mar. 4, 1927, pp. 274-275, 6 figs. Investigations in order to discover reason why set of gripping tongs on newly built soaking-pit crane would not grip as desired; crane was intended to handle ingots, thickness of which varied from 8 to 20 in.; action of tongs and calculation of forces involved.

POWER PLANTS. Minnequa Steel Works Installs New Power Plant, H. W. Neblett. Power Plant Eng., vol. 31, no. 9, May 1, 1927, pp. 494-501, 14 figs. Great plant of Colorado Fuel & Iron Co. at Pueblo, Colo., uses as fuel blast-furnace gas cleaned by electrostatic precipitators, with pulverized coal as auxiliary fuel, and operates turbo-generators and turbo-blowers.

STRUCTURAL STEEL

MODERN. German Structural Steel (Die neueren Baustähle), Füchsel. Organ für die Fortschritte des Eisenbahnwesens, vol. 82, no. 5, Mar. 15, 1927, pp. 81-83. Discusses factors which influence development of high-grade steel; introduction in Germany of St. 48, a steel having minimum rupture strength of 48 kg. per sq. mm., and a silicon steel; their workability and other properties.

TIN ALLOYS

TIN-COPPER-ANTIMONY. The Tin-Copper-Antimony System (Ueber das System Zinn-Kupfer-Antimon), W. Bonsack. Zeit. für Metallkunde, vol. 19, no. 3, Mar. 1927, pp. 107-110, 16 figs. Determination of types of crystals in this ternary system; rules for the treatment of bearing and old white metals containing copper and tin.

TUBES

NONFERROUS METAL. Manufacture of Nonferrous Metal Tubes by Hydraulic Extrusion, W. Kurz. Metal Industry (Lond.), vol. 30, no. 13, Apr. 1, 1927, pp. 333-335, 4 figs. Methods and appliances applied in processes in Continental Europe; extruding other metals; sizes of billets for extrusion; steel tools for extrusion presses.

STEEL, SEAMLESS. Seamless Steel Tubing; A Bibliography, V. S. Polansky. Blast Furnace & Steel Plant, vol. 15, nos. 2, 3 and 4, Feb., Mar. and Apr., 1927, pp. 88-91, 133-136 and 180-182 and 192. Practically all phases of tube manufacture are covered; Pilger and Mannesmann processes receive special attention; American and foreign practice.

WELDING

HEATING SYSTEMS. Welding in Plumbing and Heating, S. E. Dibble. Welding Engr., vol. 12, no. 4, Apr. 1927, pp. 42-44, 11 figs. Experimental installation shows advantages of welding torch in assembling low-pressure heating systems.

STEEL PIPE. Welded Pipe for Water System, W. P. Brown. Welding Engr., vol. 12, no. 4, Apr. 1927, pp. 27-29, 5 figs. All field joints were acetylene welded, tank gas being used; in very deep cuts pipe was welded on high horses, lowered to 40-inch level and tied into line and then whole line lowered to bottom of ditch; saving of time and money by using welding process.

THERMIT. Mill Parts are Reclaimed by New Welding Process. Iron Trade Rev., vol. 80, no. 18, May 5, 1927, pp. 1139-1140. New improved method of making thermit weld is important economic factor in reclamation work.

WELDS

TESTS. Tests of Welds at Lehigh University. Eng. News-Rec., vol. 98, no. 15, Apr. 14, 1927, p. 619. Number of tests of welded joints and members were made at Lehigh University; planned to throw light on physical characteristics of joints made by several processes; they included tension tests of welded bars, test of square frame of I-beams and H-columns, and test of trussed joist.

WIRE

MAGNESIUM. Variation of Logarithmic Decrement with Amplitude and Viscosity of Certain Metals, C. Subbahmaniam. Lond., Edinburgh, and Dublin Philosophical Mag. & Jl. of Science (Supp. no.), vol. 3, no. 16, Apr. 1927, pp. 854-857, 2 figs. Study of behavior of wires made of three metallic elements, namely, magnesium, zinc, and cadmium.

MAGNETIC PROPERTIES. Influence of Cold Working and Annealing on Magnetic Properties of Thin Wires of Invar, Iron and Steel (Influence de l'écrouissage et du recuit sur les propriétés magnétiques de minces fils d'invar, de fer et d'acier), C. Bieler-Butticaz. Archives des Sciences Physiques et Naturelles, vol. 9, no. 5, Jan.-Feb. 1927, pp. 32-51, 2 figs. Comparison of variations of magnetization with those of internal friction and moduls of torsion in function of temperature; results show that point of magnetic transformation is not displaced by cold working, but cold working changes form of magnetization curve.

WIRE, COPPER

MANUFACTURE. Developments in the Manufacture of Copper Wire, J. R. Shea and S. McMullan. Bell System Tech. Jl., vol. 6, no. 2, Apr. 1927, pp. 187-216, 26 figs. New copper rod and wire mill located at Western Electric Co.'s plant at Chicago; survey of copper-rolling and wire-drawing art; tests made in varying practice in rod rolling and wire-drawing; work done by Western Electric Co. engineers in developing and designing new types of wire-drawing machinery.

FUNDAMENTAL RESEARCH IN STEEL MANUFACTURE

(Continued from Page 914)

others have thought about steel from the colloidal standpoint. If steel manufacturers and steel treaters would stress the importance of colloidal chemistry research in relation to steel making, I think the solution of the problem of better steel production will be largely solved.

Answering Mr. Palmer's remarks, I am sorry if, in reading the paper, he obtains the impression which he has recorded. In the first paragraph under "Non-Metallic Content of Steel" I tried to give the impression that "clean steel" was a question of degree, and not that the open-hearth man was helpless, but, on the other hand, I do believe that 99 per cent of your test bars out of one heat is exceptional, and I do not think you will find many open-hearth superintendents who would not agree that it is exceptional. They will talk about clean steel all right, but just what is "clean steel?" For instance, on one heat we found the per cent of non-metallics 15 minutes after an ore addition was .001. .0012 is the per cent of non-metallics as determined by this new method, Dickinson's method, the British method, and it apparently is a very reliable method, from all the laboratory results you can get on various results of steel. Of course, I would call that a perfectly clean steel. I do not think .001 something would be in the least bit harmful, but the point is that you go from .001 on up to some unknown figure and that you have got to find out just what those different figures are.

The physical chemist and the colloidal chemist, if they could fill in some of the gaps between room temperature work and steel temperature work, we might have a little better idea of what was going on, and I do not know but what the best method of attack in that kind of work is to obtain data all the way from room temperature to steel temperatures, as it is certain that data in the 1000 degree Cent. range would be very helpful in analyzing conditions at 1600 degrees Cent.

News of the Society

THE SPRING SECTIONAL MEETING

A MOST successful sectional meeting was held in Milwaukee on Thursday and Friday, May 19 and 20. This meeting was the tenth sectional meeting of the Society, and was well arranged by the energetic Milwaukee chapter committees. The meetings were held in the Hotel Pfister, and were attended by a surprisingly large number of members and guests of the Society.

On Wednesday, May 18, the Officers and Directors of the Society and members of the Recommended Practice committee held all-day executive sessions for the discussion of Society matters. After these meetings the "Early Birds" dinner was held in the Hotel Pfister, and was followed by a theater party. A large number of the Milwaukee Chapter members attended these last two events.

At 9:00 a. m., Thursday morning, regular registration of members and guests was begun, and at 10:00 o'clock the first technical session was called to order. Chairman R. A. Thornberry of the Milwaukee Chapter introduced President J. Fletcher Harper, who extended greetings to the assembled members and guests. Dr. John A. Mathews was then introduced as chairman of the technical session. Two papers were scheduled for the session. They are as follows:

Scientific Research and Its Application to Industry, by T. McLean Jasper, director of research, A. O. Smith Corporation, Milwaukee.

The Automatic Electric Furnace—Its Uses and Possibilities, by Harold F. Wood, chief metallurgist, Ingalls-Shepard Division, Wyman-Gordon Company, Harvey, Illinois.

Thursday afternoon was devoted to a plant inspection trip to the Allis-Chalmers Company. A complimentary luncheon was served by the Allis-Chalmers Company to approximately 100 members.

At 7:00 p. m. the usual banquet was held in the Ball Room of the Pfister Hotel, and was attended by 375, the largest attendance at any of the sectional meeting banquets. President Harper acted as toastmaster, introducing the speakers of the evening. S. M. Havens, past director of the society, presented a most interesting talk on the subject of

The Technical Organization in Industry.

In this talk the speaker discussed the importance of the technically trained man in the development of the manufacturing industry. He stressed the importance of the research and control laboratories pointing out that they are as necessary as the foundry, the forge shop and other direct production departments.

The second speaker was Dr. Max Mason, president of the University of Chicago, who presented a masterly address on the relationship of science to industry entitled,

Formalism and the Deeper Insight

Dr. Mason traced the development of science throughout the ages and the

importance of the scientific mind in the development of the world and industry. He discussed the effect of the many great scientific discoveries that have been made from age to age, and how each of these discoveries have affected the lives of all mankind.

On Friday, May 20, two technical sessions were held, one at 10:00 a. m. and the second at 7:00 p. m. Each of these sessions was very well attended and interesting. Instructive discussions followed the presentation of each of the papers. The papers presented in the morning are as follows:

Heat Treatment of Wrought Aluminum Alloys of High Strength, by R. S. Archer, research bureau, Aluminum Company of America, Cleveland.

Application of Theory to Practice in Heat Treatment of High Speed Steel, by R. M. Sandberg, assistant manager, Columbia Tool Steel Company, Chicago Heights, Illinois.

The papers presented in the evening were:

Case Carburization of Steels by Means of Salt Baths of Low Cyanide Concentration, by H. B. Northrup, J. W. Kelley Company, Cleveland.

Processing Welding Wire and Its Effect on the Flow of Welding Metal, by J. B. Green, research department, Chicago Steel and Wire Company, Chicago. (Illustrated with stereopticon and movies.)

Professor H. M. Bolyston acted as chairman of the morning session and A. H. d'Arcambal of the evening session.

Plant inspection trips were arranged with practically all of the manufacturing plants of interest to members of the society, and the society is indebted to the officials of these plants for their courtesy in acting as hosts.

The members and officers of the Milwaukee Chapter are to be congratulated for having so successfully carried through the innumerable details connected with the successful conduct of one of the best sectional meetings ever held by the society.

A NEW CHAPTER

ON Thursday evening, May 26, 1927, the inauguration of the 35th chapter of the society took place in the club rooms of the Canton Club, at Canton, Ohio. This new chapter is to be known as the Canton-Massillon Chapter and starts its career with 121 members, the largest initial membership of any A. S. S. T. chapter.

The formation of this chapter was the culmination of a general ideal on the part of the members of the society living in the area comprising the cities of Canton, Massillon, Alliance and Akron, that they wanted a chapter in that district. Therefore, an organization committee was chosen, being made up of L. D. Gable, Chairman; Robert Sergeson, Secy.; Committeemen, E. C. Smith, T. W. Hardy, F. F. Dore, D. D. Reed, W. S. Carnes and M. H. Schmid to investigate the possibilities of a chapter in the Canton-Massillon district. As a result of their efforts, the committee decided that there was a sufficient demand for such a chapter, and so petitioned the national Board of Directors for a charter. Following the granting of a charter on April 20th, the following men were nominated and in turn elected by letter ballot. The officers and committees are as follows: Chairman, M. H. Schmid; Vice-Chairman, E. W.

Hanna; Secy.-Treas., Robert Sergeson; Executive Committee, E. C. Smith, F. F. Dore, L. D. Gable, T. W. Hardy, C. E. Woodfeld, P. M. Snyder, W. M. Lindsey and D. D. Reed.

On May 26 the Canton-Massillon Chapter held its opening meeting, at which time 150 members and guests assembled in the club rooms of the Canton Club for a dinner meeting. Following the dinner, Chairman Schmid introduced President J. F. Harper, who in turn presented him with the charter for this chapter.

After introductory talks by Past President W. S. Bidle and Secretary W. H. Eisenman, Dr. Zay Jeffries presented a paper entitled "The Metals of Industry." This paper was indeed most interesting and instructive, and was thoroughly enjoyed by all who had the privilege of hearing it. Dr. Jeffries discussed in a clear cut way the advances which have been made in the science of metals and pointed out that many new alloys will be developed in the future for the benefit of mankind. He called attention to the fact that a number of the members of the society contributed no small part in the development of suitable alloys and heat treatments which resulted in the successful flight of Captain Lindbergh across the Atlantic Ocean.

About 25 members of the Cleveland Chapter attended this initial meeting of the Canton-Massillon Chapter for the purpose of showing the good will which exists in the Cleveland Chapter toward the newly formed one. Nearly 50 per cent of the members of the Canton-Massillon Chapter were originally members of the Cleveland Chapter, thus depleting the roll of the Cleveland Chapter by a considerable number. However, the officers and members of the Cleveland Chapter were unanimous in their approval of the formation of this new chapter, even though it did reduce the membership standing of the Cleveland Chapter to that of 5th place. This was expressed in a short talk by H. H. Smith, Chairman of the Cleveland Chapter, and also by the following letter which was directed to the Canton-Massillon Chapter from the officers and members of the Cleveland Chapter and signed by Secretary J. S. Ayling:

> "The Cleveland Chapter through its officers have instructed the writer to express to the officers and members of your new organization their best wishes and heartiest congratulations on the founding of your Chapter.
>
> "Although many of your members formerly were listed with Cleveland, yet we all feel the organization of your new Chapter will be of great benefit both to the National Society and to yourselves as individuals.
>
> "Your members should be able to attend regularly without the inconvenience of traveling so far and subjects can be selected for your papers and talks which may be of greater interest to your members than is possible with a scattered membership.
>
> "Much as we regret the loss from our Chapter of such fine fellows yet we are very pleased to repeat that we are sincere in extending our heartiest best wishes for a very successful organization.
>
> "We trust you will prosper and grow rapidly as a part of the most successful society that we believe has ever been organized."

With this auspicious start the Canton-Massillon Chapter bids well to be one of the outstanding and progressive factors in the growth and development of the Society.

News of the Chapters

STANDING OF THE CHAPTERS

DURING the month of April there were 143 new and reinstated members, while 58 were lost through arrears and resignations, leaving a net gain for the month of 85 as compared with a gain of 88 last month and a gain of 122 in April of last year.

In the following tabulation there appears the relative membership standing of the 30 chapters and 3 groups of the Society as of May 1, 1927.

GROUP I		GROUP II		GROUP III	
1. Detroit	429	1. Hartford	138	1. Los Angeles	78
2. Chicago	406	2. Milwaukee	133	2. New Haven	77
3. Philadelphia	346	3. Lehigh Valley	125	3. Tri City	75
4. Pittsburgh	338	4. Golden Gate	116	4. Washington	70
5. Cleveland	333	5. Indianapolis	96	5. Rockford	66
6. New York	281	6. Cincinnati	95	6. Southern Tier	63
7. Boston	258	7. Montreal	94	7. Rochester	60
		7. Dayton	94	7. Toronto	60
		9. Syracuse	90	7. Worcester	60
		10. St. Louis	86	10. Providence	54
		11. Buffalo	62	11. Schenectady	45
		12. North West	55	12. Fort Wayne	44
				13. Springfield	32
				14. Columbus	32

GROUP I—There has been another rearrangement in this group. Cleveland suffered a loss of 67 members last month due to transfers to new groups and chapters, which places them in position No. 5, in close proximity to Philadelphia and Pittsburgh. Four of the chapters in Group I showed gains for the month, while Philadelphia and Cleveland showed losses.

GROUP II—Hartford still leads the group with the same membership as last month. Milwaukee shows an increase and is gradually climbing toward the top and has hopes of overtaking Hartford's lead. Lehigh Valley, Golden Gate and Indianapolis have positions 3, 4 and 5, although all of these chapters showed slight losses for the month. Cincinnati by experiencing a gain displaced Montreal from 6th place. Dayton last month showed 55 members, and now has 94 paid up, which causes it to go into a tie with Montreal. Dayton has approximately 20 applications in the office that have not yet paid, which will bring this chapter well forward into competition for positions 3 or 4. Syracuse, St. Louis, Buffalo, North West occupy the other positions.

GROUP III—There certainly were some surprises in this group. Last month we stated that Tri City Chapter were sending in 11 new applications. These applications were received, but the applicants had not qualified up to

May 1, 1927, by payment of their dues. An applicant for membership is not counted as a member of a chapter until the dues are paid, consequently none of the applicants have as yet been counted to the credit of Tri City, but will be later. In the meantime Los Angeles with a gain of 3 jumped into position No. 1, with New Haven and Tri City following. Washington and Rockford are in the same position as last month. Southern Tier took a big jump! This enthusiastic group of cities along the southern border of New York got it into their heads that they wanted to be in some place else than No. 10 (as shown on last month's report), so they sent in 10 applications with money, and now Southern Tier has 63 members and are occupying 6th place.

It seems almost impossible to break this "triple tie" that has existed for the past several months with Rochester, Toronto and Worcester, all of them having 60 members each. Providence, Schenectady, Fort Wayne and Springfield are in the same positions as last month while the new Columbus Group has 32 paid up, but is expected soon to pass this point and be in competition with position 10. The total membership of the A. S. S. T. on May 1st was 4609.

BOSTON CHAPTER

The annual meeting of the Boston Chapter was held at the plant of the United Shoe Machinery Corporation, Beverly, Mass., on Friday, May 6, 1927. This great plant, devoted entirely to the manufacture of machinery for making and repairing shoes, consists of sixteen buildings of reinforced concrete with floor space of over 21 acres. The manufacturing buildings are 1,120 feet long, 60 feet wide and four stories high. A large foundry with a daily capacity of 50 tons of castings, and a large drop forge shop adjoin the machine shops. Over 2,000 tons of bar steel, consisting of a variety of analyses, are carried in stock for use in manufacturing. More than 90,000 catalogued machine parts are carried in the finished stock room, over 21,000,000 being shipped from this stock annually. The yearly capacity of the plant in new machinery exceeds 24,000 machines.

A very extensive heat treatment department is maintained for hardening and carburizing machine parts and tools. Sand blasts are used as an aid to inspection of hardened work and there are several installations of sand blast machines for this purpose. To prevent rusting in process, stores and shipment, the sandblasted parts are immersed in a hot paraffin bath, the excess paraffin being removed by a centrifugal extractor.

After the inspection trip, the United Shoe Machinery Athletic Association extended to the visitors the use of their beautiful club house and grounds where baseball, quoits, tennis, bowling and pool were enjoyed for two hours before dinner. The day was ideal and many of the members preferred to spend their time on the porches of the club house, where an excellent orchestra turned out jazz and otherwise.

Dinner was served at 6:00 p. m. to 165 persons and the surprise of the evening came when National President J. Fletcher Harper, and National Secretary W. H. Eisenman were escorted into the dining hall by A. O. Fulton, general chairman of the Boston Convention in 1924. The visitors were given rather a noisy welcome. A business meeting was held immedi-

ately following the dinner and the Secretary's report showed that the assets of the chapter were nearly $2,500.00 and that there had been a gain of 10 per cent in membership during the past year. The following officers for 1928 were elected by ballot:

Chairman: Leslie D. Hawkridge,
Vice-President Hawkridge Brothers Co., Boston.
Vice-Chairman: Harrison B. Parker,
Foreman Heat Treating Dept., Trimont Mfg. Co., Roxbury.
Secretary-Treasurer: Howard E. Handy,
Metallurgist, Saco-Lowell Shops, Lowell, Mass.

After a few words of greeting from President Harper and Secretary Eisenman, Past Chairman V. O. Homerberg gave a brief outline of the educational course in metallurgy to be conducted by the Boston Chapter at Technology this coming winter. An address of welcome by G. T. Thomas, plant superintendent of the United Shoe Machinery Corporation, was followed by a half hour talk by Major Charles T. Cahill, of the same organization, who gave a brief history of shoes and the machinery for making them. This talk was especially interesting as almost all of the important developments of shoe making have originated in the immediate vicinity of Boston.

The principal speaker of the evening was J. C. Kielman, assistant superintendent of the forge department of the New Departure Manufacturing Company at Bristol, Conn., who presented a talk entitled, "Forging by the Upset Method". Mr. Kielman's talk concerned principally the forgings used in the manufacture of ball bearings and was fully illustrated with lantern slides. The ball race steel and its peculiarities, as well as the method of forging, were discussed. A portion of the talk was devoted to an explanation of the upsetting process and how it applies to the manufacture of ball bearing races, its advantages being shown and compared with other methods of forging. The problems of forging dies and the steels used in making them were dicussed, the importance of their proper heat treatment being emphasized. The design of the heating furnaces and methods of upkeep and repairs were described in detail. After the discussion Mr. Kielman was given a rising vote of thanks.

The program of the day was under the general direction of L. D. Hawkridge and H. B. Parker. They were ably assisted by W. R. Hurd, 2nd, A. L. Collier and P. R. Bosworth of the United Shoe Machinery Corporation. The visitation will be long remembered by those who attended and the officers and executive committee of the Boston Chapter wish to express their appreciation for the wonderful reception given the chapter by the officials, and the whole organization, of the United Shoe Machinery Corporation.

H. E. Handy.

CHICAGO CHAPTER

The closing technical meeting of the year was held at the City Club, May 12, 1927. Mr. R. J. Allen, metallurgist with the Rolls Royce Company of America, presented a paper on "Inspection and Testing of Materials as Used in the Automobile", illustrated with slides. The paper

was so well given—that when Mr. Allen got through—there was very little discussion. The following officers were elected for the coming year: Chairman, T. E. Barker, Accurate Steel Treating Company; Vice Chairman, A. M. Steever, Great Lakes Forge Company; Secretary-Treasurer, A. G. Henry, Danly Machine Spec., Inc.

Members of the Executive Committee are: A. W. Anderson, Claud S. Gordon Company; Walter Dant, Pullman Manufacturing Company; S. A. Richardson, Interstate Iron & Steel Company; C. N. Rutledge, Columbia Tool Steel Company; W. A. Scheuch, Western Electric Company.

CINCINNATI CHAPTER

S. P. Rockwell, inventor of the Rockwell Hardness Tester and the Rockwell Dilatometer, spoke before the Cincinnati Chapter of the American Society for Steel Treating on the evening of March 10, on the Volcrit method for heat treating steel. This method consists in measuring the change in the length of the piece of steel as it is heated to the hardening temperature. As the steel passes through its allotropic changes a dimensional change occurs which is clearly shown on the expansion-time curve.

Mr. Rockwell presented a number of charts showing the expansion curves typical of a number of carbon and alloy steels. In a number of cases the effect of the alloying elements on the shape of the expansion curve was very definite, and in all cases the end of the critical range was clearly shown, giving a very definite indication of the lowest quenching temperature that would give full hardening.

A number of installations of the Volcrit equipment on furnaces of various types were shown. The application of this method to hardening certain types of tools, gears and dies was described.

The meeting closed with an interesting discussion regarding the application of the Dilatometer to specific problems.

At a special March meeting of the Cincinnati Chapter, Dr. William Blum, in charge of the electrochemical division of the Bureau of Standards, addressed a joint meeting of the American Society for Steel Treating, American Society Mechanical Engineers, American Chemical Society and the Cincinnati Engineers Club on the evening of March 24, the subject being "Chromium Plating." The utility of chromium plate on various classes of tools, dies and gages was pointed out as well as the limitations of chromium.

On printing plates, chromium has proved very valuable, the life of the plate being greatly increased, while the quality of the resulting impression is materially improved. Chromium plated gages may be used indefinitely. They give long service before wearing undersize and when worn may be deplated, replated and lapped to size again. Chromium is very useful on draw dies due to the absence of any tendency of the metal being drawn to stick to the die or for the die to score. On certain dies used for coining nickels, the life of one part of the coining die was increased about five times by the application of .0005-inch of chromium.

The standard plating bath consists of chromic acid, chromic sulphate and a small amount of chromium carbonate. The bath is preferably operated at

45 degrees Cent. The current density and the temperature must be accurately controlled for satisfactory results. *E. M. Wise.*

W. P. Sykes, metallurgist of the Cleveland Wire Works of the National Lamp Division of the General Electric Company and chairman of the Cleveland Chapter of the American Society for Steel Treating, spoke on the evening of April 7, describing his work on the Iron-Molybdenum system.

Certain of the alloys of this system show marked age hardening after quenching from about 1400 degrees Cent. and aging in the vicinity of 650 degrees Cent. which renders them very valuable for swaging dies for hot swaging tungsten and molybdenum. After quenching and before aging the 20 per cent Mo alloy is soft enough to be machined to form. After aging the Rockwell hardness will approximate 63 C. This hardness will be retained for many hours at temperatures causing the rapid softening of high speed steel. It has been found that the life of a hot swaging die of this material is about 50 times that of the best high speed steel.

Molybdenum alloys containing small amounts of iron also show age hardening and are used for draw dies for drawing tungsten wire.

These alloys are interesting examples of the general phenomena of age hardening and are indicative of the trend of metallurgical advance.

News of the Evening Course in Metallurgy

In line with the national policy of the American Society for Steel Treating of encouraging adult education, the Cincinnati Chapter of the American Society of Steel Treating investigated the possibilities of establishing evening courses in metallurgy and heat treating for the benefit of the men who are employed in metallurgical industries in Cincinnati. Upon investigation, it was found that evening courses could be given as a part of the regular work in the evening school of the college of engineering and commerce of the University of Cincinnati. Accordingly, the local chapter sponsored the establishment of courses in metallurgy and heat treating and activity co-operated in placing the advantages of these courses before those who might be interested. The work of the educational committee deserves much credit.

During the first semester a course in general metallurgy was offered. This course included a discussion of the properties of metals, furnaces, fuels and refractories, a discussion of pyrometry, and of the metallurgy of iron and steel. Wherever needed, a review of the fundamental principles of chemistry and physics was introduced. For the work of the first semester there were no pre-requisites. The course was open to any who might care to attend. The course as given included numerous lecture demonstrations and a liberal use was made of lantern slides. Eighty-three men registered for this course, coming from forty-five different companies. Of this group of men, about fifty per cent were executives, draftsmen, chemists, etc., while the other fifty per cent were skilled workmen. A course of sixteen lectures was given, each lecture period lasting one hour and a half. The class met in the Chemistry Building at the University of Cincinnati at 7:30 p. m. on Wednesday evening.

During the second semester, a course in heat treating was offered. In order to take this course, the student was required to have taken the course in general metallurgy mentioned above or to have equivalent training. The subject matter of the course embraced elementary physical metallurgy and all of the other subjects given in a heat treating course. The class met at 6:30 p. m. on Wednesday evening. Lectures were given from 6:30 to 8:00 and laboratory work from 8:00 to 10:00 p. m. The metallurgical laboratories of

Evening Class in One of the University Laboratories.

the University of Cincinnati are among the best equipped in the United States, and adequate facilities were available for laboratory work. The course embraced sixteen lectures and laboratory periods. A class of forty-seven men registered. Many of the men who took the course in the first semester were interested only in general metallurgy. Practically all of those who were interested in heat treating enrolled for the second semester, and a few who had not taken the first semester's work also enrolled.

The regular lecturer during both semesters was Dr. G. M. Enos. During the first semester, two special lecturers were brought in and the class thrown open to the public on these two evenings. During the second semester, the staff of instruction consisted of Dr. Enos, in charge, Professors McDuffie and Bradley. There were also employed a librarian, a laboratory assistant, and a mechanic. With this staff, it was possible to give very thorough and personal instruction. The work has been so successful that it is planned to offer additional courses during the coming year, as well as to offer again the same courses as were given during 1926-27. These new courses will em-

brace a course in advanced heat treating and metallography and possibly courses in foundry practice and electro-metallurgy.

Among those members of the local chapter who deserve especial credit for their work in promoting the courses are:—W. R. Klinkicht, our chairman, and A. J. Lucas, the vice-chairman. Many members of the Society took a personal interest in the work and also a considerable number of the local chapter registered for the course.

COLUMBUS GROUP

Friday, April 29, marked the installation of a new group at Columbus, Ohio, with an initial membership of 45 members. Of this number 7 are of the sustaining class, evidence of the splendid support given by the industries of the community.

Prof. J. O. Lord and G. S. McFarland saw the possibilities of a group in Columbus. W. H. White had laid the foundations by the nucleus he had built in Columbus as an adjunct of the Cleveland Chapter. At a request to the National Office, H. Kenneth Briggs, assistant secretary, spent some time in Columbus assisting in the preliminary work.

The first meeting at the Neil House was attended by more than 80 guests and members. Prof. Lord, chairman of the organization committee, gave a brief outline of the formative period. The new officers were then elected. Mr. Eisenman gave an interesting history of the Society, outlined its activities, and presented the charter.

After the preliminaries, J. A. Succop of the Heppenstall Forge and Knife Company presented some films entitled, "The Story of the Die Block." The pictures and Mr. Succop's very interesting and useful talk were well received. Those present kept Mr. Succop talking and answering questions until nearly train time.

The May meeting was announced for Tuesday, May 24, when F. E. Palmer of the Carpenter Steel Company will talk.

The newly elected officers are as follows: chairman, G. S. McFarland, 600 Joyce Realty Bldg.; vice-chairman, S. Z. Krumm, Buckeye Steel Castings Company; secretary-treasurer, G. D. Moessner, Buckeye Steel Castings Company. Executive Committee: Prof. J. O. Lord and Prof. John Younger of Ohio State University; R. T. Dawson, Jeffrey Manufacturing Company; E. B. Furry, Ralstone Steel Car Company; R. E. Christin, Columbus Bolt works; H. B. Kinnear, Marion Steam Shovel Company, Marion, Ohio; B. C. Thiel, The C. & G. Cooper Company, Mt. Vernon, Ohio.

The fine attendance and the enthusiastic reception of the first speaker indicate the fine spirit of the Columbus Group. These things make for its success.

DAYTON CHAPTER

The May meeting of the Dayton Chapter was held on Monday evening, May 16, in the auditorium of the Engineers' Club and was attended by 135 members and guests. At a short business session it was decided to hold a get-together and get-acquainted dinner in June.

E. C. Smith, assistant general superintendent of the Central Alloy Steel Company was the speaker. In the first half of his talk, which was illustrated by slides, he discussed the manufacture of high grade alloy steels, starting with the method of charging the open-hearth furnace, working and pouring the heat, breaking the ingots down into blooms and billets, and rolling the semi-finished material.

The discussion that followed this first half of his talk centered around the production of high quality alloy steels. Mr. Smith brought out the advantages of the big-end-up ingot for minimizing pipe and segregation. By the use of the big-end-up mold of the proper design, together with a refractory sink head, the pipe and its accompanying segregated area, instead of being a pencil-shaped cavity far down into the body of the ingot, is brought up into the upper 20 per cent of the ingot where the unsound material can be cropped and scrapped with a minimum loss.

Finishing temperatures for rolling alloy steels and their effect on the quality of the steel were also discussed.

The second half of the address was on alloy steels. In starting his discussion Mr. Smith defined alloy steels and the various major groupings, i. e., the nickel, chromium, chromium-nickel, chromium-vanadium, etc. Taking each group, the speaker called attention to their advantages and disadvantages. He brought out the fact that there is no ideal alloy steel, but there is an alloy steel which is best for each purpose.

The speaker brought out the effect of the alloying metal on the steel, for example, the effect of vanadium on grain size, and the excellent carburizing properties of nickel and nickel-molybdenum steels. The molybdenum alloy steels were discussed at length especially concerning the relative ease of machining them after heat treatment.

Among other interesting details brought out by the speaker was a comparison of carbon and chromium steels for carburizing, the necessity of care in heat treating carburized objects, the characteristics of water and oil hardening steel as regards distortion and change of length in heat treatment, the advantages of liquid baths for heating for hardening as compared with the lead pot and electric furnace.

A lively discussion followed the second half of the talk.

F. T. Sisco.

GOLDEN GATE CHAPTER

The Golden Gate Chapter did not hold its regular March meeting due to the fact that every effort was being used to make a success of the course in heat treating which was started at the Oakland High School on March 8. The school has proven very successful, having an attendance ranging from 60 to 100 members.

The April meeting was held on the 13th of the month at the Engineers Club, San Francisco, and proved to be one of the most interesting and best attended meetings of the chapter. Eighty-five attended the dinner and 125 the meeting which followed. This is the largest recent attendance the chapter has had except for the special meeting which was held at Stanford in February at which there was a total attendance of over 250.

Fred Wight was chairman of the evening and he introduced T. W. Brooks, assistant sales manager, tube department of the United States Steel Products Company. Mr. Brooks gave a complete presentation of "Wrought Pipe from Ore to the Finished Product." This was vividly presented by means of a number of reels of moving pictures accompanied by explanatory remarks.

F. G. Harmon, technical engineer, in the research department of the National Tube Company, further developed the subject presented by Mr. Brooks by delivering an instructive talk on "Corrosion." This second address by Mr. Harmon was in a way a supplement to a previous lecture which he gave on the subject of "Corrosion" sometime ago before the Golden Gate Chapter. The very severe condition of corrosion existing on the Pacific Coast has warranted the Golden Gate Chapter investigating this subject in detail.

C. R. Owens.

LEHIGH VALLEY CHAPTER

The April meeting of the Lehigh Valley Chapter was held on April 14, 1927, at the Elks Club in Phillipsburg, N. J., as a chapter dinner meeting, at which we had present 260 people. The idea of a chapter dinner meeting is a new one for Lehigh Valley and the turnout we had was most gratifying, and indicates that a dinner such as this, two or three times a year, would be appreciated and heartily backed by our entire chapter.

The number of men at this meeting, who are not members of our Society, is an indication that our chapter is getting more attention and thought than we realized. No membership drive was made at the meeting to obtain new members, but we feel that this contact will eventually bring to us more men who formerly have not displayed any particular interest in our meetings.

The program of the meeting included an address by Major R. A. Bull, research director of the Electric Steel Founders Research Group on the subject of "Steel Casting". Major Bull's address covered the early history of steel casting and the development of this product to its present day high standard. The subject was covered in detail from a historic standpoint, and the production figures quoted by Major Bull were of interest to all, indicating the rapid growth of electric steel casting.

Another feature of our program was the showing of two (2) films, recently released by the E. I. Dupont Company, and loaned to the chapter for this occasion. The first film showed the manufacture of dynamite, and the second the building of New York's newest subway. This being a current topic was of much interest to the crowd, and we feel no hesitancy in heartily recommending these films to any chapter which might be interested along these lines.

The Lehigh Valley Chapter felt particularly fortunate in having with them their old friend and past president, "Bob" Bird. Mr. Bird was only one of a number of outside men who came to Phillipsburg to attend this meeting. We cannot help but feel that the presence of members from other chapters is an indication of the wide-spread interest held by our Society in this locality.

J. H. Stoll.

LOS ANGELES CHAPTER

Another plant visitation on March 12 gave the members and prospective members of the Los Angeles Chapter an opportunity to see how the Emsco Derrick and Equipment Company of Los Angeles, Calif., carries on its extensive business in the manufacture of steel oil derricks and oil well drilling equipment.

Through the courtesy of William Parker, plant superintendent, arrangements were made for a Saturday afternoon visit while the entire plant was in operation. This arrangement gave most every member of the chapter an opportunity to be on hand, resulting in a very good attendance.

Starting in the machine shop, the visitors were shown many of the processes used in the making of drilling equipment. Following this the route led through the light and heavy forging shops where much of the raw material is formed for the subsequent machine work. Through large storage yards filled with large stocks of material ready for immediate shipment and large quantities of raw stock, the visitors were next taken to the fabricating shops, sheet rolling and welding shops. The galvanizing plant, the largest on the Pacific Coast, was next visited. Enormous quantities of derrick frame parts are here treated and galvanized to withstand the climate in any part of the world.

Last but not least was the heat treating plant, up to date in every respect with fine furnaces, oil baths, recording and testing instruments. In spite of almost continuous operation for some time past, this department was as clean and orderly as a new room.

Mr. Fisher, head of this department, and his assistants were present to receive the visitors and answer questions. Much interest was displayed in this and all other departments, and after a vote of thanks to Mr. Parker and the group leaders, the visitors left the plant feeling that the plant inspection was one of our most successful meetings.

The April meeting of the Los Angeles Chapter was held April 12, at the Los Angeles City Club, at which time the 45 members and guests present enjoyed a good dinner. We, of the Los Angeles Chapter, feel fortunate when we have a big man from the steel business in the east address our chapter. At this time we were honored by having as our guest "Bob" Shimer, metallurgist for the Bethlehem Steel Corporation. Mr. Shimer confined his talk to "Modern Phases of Metallurgy" which all present found very interesting. After his talk, a very interesting discussion ensued, "Bob" standing up under a barrage of rapid-fire questions from the listeners that would have tested the metal of the best of them in the game.

E. C. Black.

MILWAUKEE CHAPTER

The Milwaukee Chapter held its last monthy meeting of the season on Monday, May 16, at the Republican Hotel. The dinner at 7 o'clock was attended by 30 and the attendance for the meeting was about 80. The speaker of the evening was David McLain, President McLain's System, Inc.

Mr. McLain gave a paper on the use of steel and scrap iron in the blast

furnace and its resultant effect on the pig iron produced. Some thirteen elements existing in pig iron which are rarely ever considered when making an analysis, as well as the grain structure, were mentioned by Mr. McLain. Gray iron and semi-steel foundry practice, mixtures and cupola operation were also touched upon. The many questions and much discussion were evidence of the interest in iron foundry practice.

One paramount discussion was "the effect of varying percentages of steel on the total carbon present in the iron after passing through the melting zone, out of the cupola tap and into the ladle". Mr. McLain's answer to this was, as many of us have experienced, that there was no difference in the amount of total carbon present due to any precentage of steel used in the cold charge, but that the construction, operation of the cupola and temperature were the controlling factors in this connection.

J. Fletcher Harper, President of The American Society for Steel Treating was present and he gave us some interesting information concerning the manner in which the visitors and members attending the Sectional Meeting will be entertained.

Milwaukee Chapter wishes to express its thanks and appreciation to Mr. McLain for his very interesting talk. *M. E. Greenhow.*

NEW HAVEN CHAPTER

Well! Thursday, May 12th, was surely another big day for the New Haven Chapter. It was predicted last fall that our get-together dinners were so well attended as to warrant holding them monthly and from the crowd present in Waterbury on the 12th, I should say the prediction was well founded.

After having the inner man well satisfied, we journeyed over to the office building of the Chase Companies where the first speaker of the evening, Dr. Colin G. Fink, of Columbia University, spoke on "Chromium Plating", and it is the writer's opinion that from the number of questions asked, the subject was one that seemed to interest everyone present very keenly. The speaker showed some very interesting specimens of chromium plating and it was indeed to be regretted that he had to catch an early train.

The next order of business was the report of the Nominating Committee by the Chairman, R. S. Young. The following were then elected for the ensuing year, viz.:—

Chairman:—W. Paul Eddy, Jr., Geometric Tool Co., New Haven.

Vice Chairman:—Harold Fish, Ready Tool Co., Bridgeport.

Secretary:—F. E. Stockwell, Standard Oil Co., of N. Y., New Haven.

Treasurer:—Walter G. Aurand, R. Wallace & Sons Mfg. Co., Wallingford.

Those elected for the Executive Committee are:—R. L. Baldwin, Bridgeport; T. H. Chamberlain, New Haven; R. G. Hall, Wallingford; J. T. Kemp, Waterbury; H. G. Keshian, Waterbury; G. C. Thomas, Bridgeport.

Delegate to National Nominating Committee:—C. J. Sauer, Bridgeport, with F. E. Stockwell, New Haven, as alternate.

The new chairman has appointed the following as additional members of the Executive Committee, viz.:—F. J. Dawless, New Haven; W. H. Duley, New Haven; A. Phillips, New Haven; A. J. Porter, Jr., Bridgeport; C. J. Sauer, Bridgeport; R. S. Young, Shelton.

After the election of officers, our ever congenial National Secretary, "Bill" Eisenman, gave his usual interesting talk, telling us about the progress of the society and the next national convention in Detroit.

The attendance prize donated by Julius Brooks of the Sargent Company, New Haven, was won by J. C. Bradley of the American Brass Company, Waterbury.

The attendance at the Waterbury meeting was the best of the year and we were indeed glad to see so many of our old friends from Hartford with us once more, but indeed sorry to have d'Arcambal "sat on" so much. Better luck next time, d'Arc.

The writer is too full of details of the June Frolic to write much this month, but promises more the next time. Meet me at Savin Rock.

Walter G. Aurand.

NORTHWEST CHAPTER

The April meeting of the Northwest Chapter was held April 19, at which H. F. Wood of the Wyman-Gordon Company of Harvey, Ill., gave a talk on drop forgings. Mr. Wood first traced the development of the drop forging industry in this country in which he brought out the fact that the World War and the modern production of the automobile were the chief factors in bringing the industry to the position it now holds. Although there was a great depression in 1920 and 1921, at the present time all the factories that are using the improved modern methods are able to show fair profits every year. Those factories, however, which are still using the old methods are slowly losing ground.

Mr. Wood then discussed the problems confronting the drop forger. One of the most important of these is the selection of the proper steel. The chief properties a steel should have are:

Forgability; large heat treating range; readily available; freedom from defects such as pipe, segregations, snowflake and woody structures, sonims in excess, and internal ruptures; good machinability; price.

In regard to machinability the hardness can not be used as a test to decide whether or not the steel has good machining properties. The original price of the steel is not of chief importance, but consideration should be given to the cost necessary to produce the same quality product with different steel. In this way a steel having a higher original cost might prove to be the cheaper in the finished product.

The design of the dies and the parts is of next importance and should be such as to produce the best product at the lowest cost. Deep etching by means of 50 per cent HCl is used to check up the stress lines in the forgings. In all cases to get best results the stress on the parts should be perpendicular to those stress lines.

The heating of the steel for forging has to be carefully controlled in order to turn out a good uniform product. The greatest difficulty is to get

the steel to the proper temperature and avoid scaling. The first of these is accomplished by having the furnace under automatic temperature control so as to eliminate the human element entirely. By use of the automatic temperature control the company was able to increase the production 50 per cent, decrease the oil consumption in the furnace 6 per cent and get a better product. The great saving with the automatic temperature control furnace was not in the fuel consumption but in increasing the production and quality. The furnace acted as a pace-setter for the men. In order to avoid scaling, a recuperative type furnace is used which admits the air in a preheated condition making it possible to get combustion without very much excess air and thus cut down the amount of scaling.

The steel to be forged should be of the proper size to avoid excess material which would produce large flash. This excess material is very hard on the dies and is an extra expense as it has to be removed. The loss due to excess material was cut down from 30 per cent five years ago to 18 per cent at the present time. For hot trimming this flash, stellite seems to give the best results while chromium-vanadium steel is best for cold trimming.

After forging and trimming the parts are twisted or bent to the required shape and then heat treated so as to obtain the desired physical properties. The final heat treatment is done entirely in electric furnaces with automatic temperature control which eliminates the human element entirely and produces a uniform product. Each piece is quenched individually and the quenching medium should be selected so as to give the properties desired with the minimum amount of distortion and cracks. Mr. Wood brought out the interesting fact that in his experience, in order to get consistent results, the heat treatment should be governed by the steel mill rather than by chemical analyses. In other words, two different heats may have the same chemical anlaysis but would not give the same properties with the same heat treatment.

After heat treatment, the parts are inspected 100 per cent for Brinell hardness, surface defects after sand blasting, angularity and finish. About 30 per cent of the steel is analyzed chemically before it is used to make sure that it has the proper composition.

L. J. Weber.

PHILADELPHIA CHAPTER

Steel Treating Class Demonstrates Work

Modern methods in the study and treatment of steel were demonstrated at the third annual exhibit given by the co-operative evening class in heat treatment and metallography of steel, conducted under the auspices of the Phila. Chapter, American Society for Steel Treating, at Temple University, on May 19th and 20th. There was a large attendance of technical and practical men from local industries.

In point of equipment, the metallurgical laboratory now ranks among the best in the country. More than 200 students have attended this course, the present year's enrollment having been 55, with 10 in the advance class.

An alumni association, including students of the past six years, was founded at a recent meeting.

Cooperative research with Philadelphia industries, in the solution of metallurgical problems involving annual losses of many thousands of dollars, was a special feature of the season's work.

New equipment to be added to the laboratory next fall includes an Ajax-

Photograph of Those Attending the Organization Meeting, Alumni Association, Course in Heat Treatment and Metallography of Steel, Under the Auspices Philadelphia Chapter, A. S. S. T. at Temple University, May 16, 1927.

Rear row (standing) left to right: James R. Adams, Chairman elect, Philadelphia Chapter; M. M. Kennedy, Instructor and member Educational Committee; A. MacLean, Jr., Chairman, Alumni Association; W. B. Coleman, Chairman, Philadelphia Chapter; Dr. James H. Dunham, Dean, Temple University; Dr. F. W. Tyson, Chemistry Department, Temple University; H. C. Knerr, Director of Course; J. P. Brown, Chairman, Educational Committee, Philadelphia Chapter; R. M. Berry, Instructor, Vice-Chairman, Alumni Association; A. L. Collins, Director Philadelphia Chapter, Member Educational Committee; Theo. Wiedemann, Member Educational Committee.

Northrup high frequency induction furnace, and probably a small arc steel melting furnace which will greatly broaden the facilities for research.

As a part of the course, the class recently made a tour of inspection through the Midvale Steel works, and also visited the heat treating department of the Wiedemann Machine Co.

The pronounced interest which this cooperative educational plan has aroused among leading industries, and the enthusiastic support of the past students, assure an increasing power for service to the community in the future.

PITTSBURGH CHAPTER

The Pittsburgh Chapter held its May meeting on the evening of the 5th at the U. S. Bureau of Mines.

A dinner was served at 6:30, after which Mr. H. L. Walker, our former Secretary and Treasurer, who has just returned from a round-the-world trip, gave an extemporaneous account of his experience which was most interesting. He pictured very vividly the present unrest in the Orient.

At 8 o'clock, Chairman W. H. Phillips called the meeting to order in the auditorium. After the routine business was disposed of, the Chapter proceeded to its annual election of officers.

The following were unanimously elected:

J. P. Gill	Chairman
W. I. McInerney	Vice-Chairman
H. L. Walker	Secretary & Treasurer

Those elected as Directors are as follows: J. L. Uhler, W. H. Phillips, S. L. Goodale, J. A. Aston, C. E. Corson, A. D. Beeken, Jr., W. B. Crowe, E. H. Dix, Jr., W. H. White, H. R. Wade.

Advisory Director, T. D. Lynch.

In expressing its appreciation to the retiring officers, the Chapter especially thanked H. R. Wade who had served as secretary and treasurer during Mr. Walker's absence.

Mr. Gill then took the chair, and, after a short speech of acceptance, welcomed Prof. W. Trinks of the Carnegie Institute of Technology who read a paper on "The Relation Between Heat Treating and Mechanical Engineering."

The author said in part that: "Heat treating is a strictly metallurgical process and it might seem that there is no connection between it and mechanical engineering. But when we look closely, we discover many points of contact. The purpose of this paper is to dwell on these relations and to show how interdependent the two sciences really are.

"In the first instance, the heat treated steel products are almost entirely used by the mechanical engineer, or in other words in machinery, it being understood that mechanical engineering is the science of machinery. Heat treated parts enter into automobiles, airplanes, gear drives, typewriters, and a host of other machines.

"As a matter of fact, it was the demand for light weight yet strong and almost unbreakable machines that gave steel treating its start. Since the demand for heat treated parts came from mechanical engineers, it might be surmised that this group of engineers is thoroughly familiar with the properties of heat treated steels and with the limitations of heat treating. But that supposition is wrong. Comparatively few mechanical engineers are conversant with the stresses which treated steels can carry with safety and with the effects of mass upon steel treating. This lack of familiarity leads to all sorts of errors.

"When it comes to carrying on the process of steel treating, the mechanical engineer is again very much in evidence with machinery because we must save labor in order to produce goods cheaply enough for mass consumption. Mechanically inclined inventors have introduced many different types of

mechanisms for automatically moving steel pieces through heat treating furnaces and for batch moving steel pieces through heat treating furnaces and for batch charging.

"Some of this progress may consist in the application of electrical heat and this thought brings me to an important part of this paper, namely, the extent to which the mechanical engineer has cheapened electrical energy in the last 25 years. Electrical heating is very efficient if we consider the heat in the charge as a fraction of the equivalent heat value of the delivered electrical energy. It is not nearly as efficient if we consider the overall efficiency from the heat in the charge to the potential combustion heat in the coal pile. If we figure with 80 per cent efficiency of the furnace, 95 per cent transmission efficiency and 3 pounds of 13500 B. t. u coal per kilowatt hour, then we obtain an overall efficiency of only 6.4 per cent, which is extremely low. If mechanical engineering had not progressed beyond the 3 pounds of coal per kilowatt hour stage, the use of electrical energy in heat treating would be very limited, because commodities and processes which are too dear will never be extensively used, no matter how many conveniences they offer. An example of the truth of this statement was given above concerning the use of alloy steel for annealing covers in sheet annealing furnaces. But, fortunately for industry, mechanical engineers have been hard at work improving boiler combustion, heat transfer, raising steam pressures and superheat, improving steam turbines, introducing regenerative cycles, air preheaters, and other improvements, until today several power plants work with a rate as low as one pound of coal or even slightly less. This rate is equivalent to an overall efficiency of 19 per cent from heated charge to coal pile. Although this value is nothing to brag about, it is acceptable, particularly in conjunction with the reduction of labor costs in power plants due to the installation of large units of boilers and of steam turbines with automatic control of combustion and with automatic lubrication.

"We are prone to say: If you want to do a thing right, do it electrically; but we are apt to forget to give credit to the mechanical engineer who slowly but steadily improves conditions in the power plant.

"At this point the question may well be asked: If mechanical engineers in the last 25 years have reduced the coal consumption rate from 3 pounds per kilowatt hour to 1 pound, can they, in the next 25 years reduce it from 1 pound to 1/3 pound per kilowatt hour? Since the rate of 1 pound corresponds to a thermal efficiency of 25.2 per cent from coal pile to generator shaft, the rate 1/3 pound per kilowatt hour would correspond to a thermal efficiency of 75.6 per cent. While this latter value is not impossible from a purely theoretical standpoint, it cannot be reached, unless we find new materials which in a white hot state are as strong as cold steel. To obtain a thermal efficiency of 76 per cent by the Carnot cycle, we must send the working medium to the prime mover at a temperature of over 1800 degrees Fahr., and we must not abstract any heat by water cooling or air cooling until the medium has expanded to room temperature by converting heat into work.

"In steam power plant practice, further improvement may be expected, but it will be slow because still higher pressures and superheats require heavier

and more expensive construction, which is not justified with the present low fuel prices. However, it is always risky to prophesy, and power plant engineering may progress faster than the present trend would lead us to expect.

"Part of the lack of progress must be laid at the door of the metallurgist. At temperatures above 750 degrees Fahr., most materials, such as steel, and even alloy steels, begin to creep, that is to say they show a very slow but steady deformation under load.

"While mechanical engineers have done quite well in cheapening the generation of electrical energy, they have, thus far, fallen down in the production of a simple all-mechanical temperature control device for heat treating furnaces. It is true that the one company has for many years had a temperature control device which is mechanical with the exception of the thermocouple, but it is not as simple as the more recent electrical devices. Yet, the latter are too complicated and expensive for small furnaces. When looking at small, electrically controlled furnaces, one cannot help having the impression that they consist mainly of a big temperature controlling device and a comparatively unimportant furnace.

"With these remarks, I might close my rather brief paper, as far as steel treating is concerned, but I wish to call your attention to another phase of heat treating which carries the work of steel treating another step further. I refer to the heat treating of aluminum alloys. For pistons and connecting rods of automobiles and airplane engines, steel is unsuitable and too heavy, and aluminum alloys have been substituted. Some of these alloys need heat treating, although it is different from the treatment given steel. The work of replacing iron and steel by aluminum alloys will go on at an accelerated rate as we learn more about these alloys, and as the latter, pound per pound become two or three times as strong as steel. Not only Zeppelins and airplanes, but automobiles, trolley cars, and railroad cars will be made of aluminum alloys. In my opinion, aluminum alloys will be just as important as steel or even more so in a period of 20 to 25 years."

After a general discussion of this paper, the meeting adjourned with a rising vote of thanks to Prof. Trinks. *Harry A. Neeb, Jr.*

PROVIDENCE CHAPTER

It was due to the personal efforts of our genial chairman, Thomas Wray, that the Providence Chapter records what was probably the most interesting meeting since its organization.

This meeting was held on the 21st of April, comprising an afternoon visitation to the Washburn Wire Company, and its subsidiary, The American Electrical Works at Phillipsdale, where light refreshments, as Mr. Wray expressed himself, were served. Later an interesting, illustrated talk by George Richardson of the Bethlehem Steel Company was given at the Providence Biltmore Hotel.

The visitation to the Washburn Wire Company was a real eye-opener, very few of us realizing that we had in our vicinity a modern and up-to-date steel mill of such magnitude. This company is not a new concern by any means and specializes more particularly in the higher grade of alloy and carbon

steels. We had the pleasure of witnessing the tapping of one of their 15-ton basic open hearth furnaces and following the ingot right down through the rolling mills to the billets and from there on to the soaking pits, rod rolling mills and dies making up the wire drawing operations. All of this was extremely interesting.

Only a high grade wire is made here and the scrap used in making the steel is given a rigid inspection. The capacity of the open hearth furnaces is 40,000 tons per year. An instance was cited which showed that they supplied steel to some of the most exacting specifications, giving as an illustration the clutch spring of a Ford and of a Rolls Royce, both being made from exactly the same steel, the former weighing 0.6 of a pound and the latter approximately 6 pounds, also mentioning the Ford Motor Car Company specifications calling for very narrow limits, such as a 0.07 per cent carbon leeway.

Leaving the Washburn Wire Company and passing to its subsidiary, The American Electrical Works, we followed the high grade copper billets from the gradual preheating furnaces through the rolling, drawing and annealing operations. Every foot of copper wire that passes through this mill is tested and the wrapping and various methods of insulating this wire for different uses was mighty interesting.

A rather unique method of making lead tubing and of forcing it over the copper cables was seen in operation. After passing the winding and cable forming machines we returned to the office and recreation building where we found out what Mr. Wray meant by light refreshments. It was quite a spread.

The regular meeting was held after dinner. Mr. Wray and his assistants thoroughly explained the whys and wherefors. A rising vote of thanks was extended to the Washburn Wire Company for their hospitality by the members present. The meeting adjourned to the ballroom of the Biltmore Hotel where George Richardson gave an illustrated talk on "Manufacture of Wire and Wire Products" to a gathering of 400 invited guests. Mr. Richardson started us off at the mine and carried us through to the finished product in a mighty interesting manner.

The members who were fortunate enough to have been able to take in the day's program should be very well versed in wire manufacture and wire drawing, and at our meeting next month, which will be a visitation to the Universal Winding Company, I can assure you of another interesting trip. The Universal Winding Company not only specializes in textile machinery but have a heat treating plant and one of the largest and most up-to-date foundries in New England. This visitation will probably also be limited to steel treaters.

E. G. Peterson.

SOUTHERN TIER GROUP

On Monday evening, March 29, at the Hotel Arlington, Binghamton, N. Y., the Southern Tier Group held its largest and most successful meeting of the year. There were seventy-five men at the dinner and the talk afterwards was heard by about three hundred and fifty people.

Mr. Sturrock, chairman, reminded the members of the goal which had

been set by the officers:—100 members by the end of the first year. He said that at present there were sixty-five members in good standing and asked that everyone get busy and put the total over the hundred mark.

The feature of the evening was a talk by G. A. Richardson of the Bethlehem Steel Company. To illustrate his talk Mr. Richardson showed several motion picture films which were remarkable for their clearness and the detail of the steel mill operations which they depicted.

At a previous meeting Mr. Richardson started with the open pit method of mining the ore. This time he began with the shaft type of mining, explaining the reason for this method of mining and how it differs from the open-pit method. He then described the bessemer and open-hearth methods of making steel and finally described the new sheet mill operated by the Bethlehem Steel Company at Sparrows Point, Maryland.

The regular monthly meeting of the Southern Tier Group was held Monday, April 25, at the Ingersoll Rand Club House, Athens, Pa. After the dinner and a short business session, J. P. Gill of the Vanadium Alloy Steel Company, talked to the members on the general subject of alloy tool steels and then led a discussion on high speed steels.

Mr. Gill presented the subject of alloy tool steels in a very simple and interesting manner. Starting with plain carbon tool steel, he described the physical constituents of the steel and then divided the alloys into two main classes—those which go into solution with the iron (the tougheners) and those which form carbides (the hardeners). He told of the effects on the steel of these two general classes. He then took in turn each element, such as nickel, chromium, manganese, vanadium, and tungsten and described its advantages and disadvantages, and in which percentages it was present in alloy steels in common use. In talking about the more complex alloy steels such as high speed steels, Mr. Gill explained the purpose of each element and how some element could be used to replace others, for example, molybdenum replacing tungsten. He discussed the limitation of such substitution, explaining the difficulty of retaining molybdenum in solution when it is present in quantities greater than 4 per cent.

The members were as one in voicing the opinion that they had spent a very profitable evening and had learned something about tool steels which would be of value to them in the future.

TRI CITY CHAPTER

Fifty members of the local chapter of the American Society for Steel Treating had dinner at the LeClaire Hotel, and later, at the Peoples Power Company's new auditorium, listened to a talk on Drop Forging by Harold F. Wood, metallurgist for the Ingalls-Shepard Division of the Wyman Gordon Company of Harvey, Illinois. This company is famous over the world for its high quality drop forged automotive crank shafts. Mr. Wood traced the development of modern drop forging from the days of the blacksmith. The growth of this important branch of modern industry is due largely to the efforts of engineers and metallurgists.

The factors which govern the quality of the forgings produced are:

proper die design, high quality of steel free from impurities, segregations, pipes, blowholes, etc., and proper forging temperatures. Failure to observe any of these factors means forgings of inferior quality and ones that may fail in use.

At the Ingalls-Shepard plant at Harvey, Illinois, temperature control is being followed for forging heats with very good results.

Mr. Wood spoke also of the heat treat practice following the forging operations. He stated that by means of large continuous electric furnaces the forgings are heat-treated with practically no direct labor cost.

WASHINGTON-BALTIMORE CHAPTER

The Washington-Baltimore Chapter held its April meeting on the 29th in the Engineers Club, Baltimore. After dinner and a short business session the speaker of the evening, F. R. Palmer, addressed the chapter on the subject "Giving Steel Tools A Chance".

There are three main points to be considered in making steel tools; chemical analysis, quality, and heat treatment of the steel. There are external and internal forces acting on tools. When the total of all these forces is in execess of the strength of the steel, the tools break.

The internal forces correspond to strains resulting from many causes These strains are very frequently evident in regular practice and are sometimes so great that the least disturbance may cause rupture. The speaker cited, as an example, the case of a steel tool, which was apparently good, chipping in his hands; the strains were so great that the expansion due to the heat of his hand was sufficient to produce fracture.

The origin of these very important internal stresses may be traced to (1) the steel itself, (2) tool design, (3) forging, (4) machining, (5) hardening, (6) tempering, and (7) grinding.

The Steel—Quality depends on purity, determined by absence of undesirable ingredients, cleanliness in respect to absence of non-metallics, and uniformity in respect to absence of differences in properties between different bars and shipments.

Tool Design—This plays a most important part in determining the strength of the tool and special attention must be paid to the avoidance of sharp corners, angular keyways, unbalanced sections, etc. A number of lantern slides showed failures due to these causes. There are, of course, cases where tools must have sharp corners, but small fillets can usually be made and ground off after heat treatment. Unbalanced sections may be avoiding by drilling holes in thick sections or plugging them up in the thin sections.

Forging—Forging is a heat treating operation. Forging can put a tool in an undesirable condition which cannot be fully offset by the following treatment. Every steel has a temperature at which it should be forged for best results and this temperature range is not as wide as frequently believed. If high speed steel which is an air-hardening steel is heated for forging to 2100 degrees Fahr. (1150 degrees Cent.) or above, and the hardening temperature is the same as or higher than that of the forging heat, then the so-called "fish scale fracture" is produced; tools in this

condition are extremely brittle. If, however, this steel is forged at 2050 degrees Fahr. (1120 degrees Cent.) or below, there is no danger of this kind unless more than one hardening is used.

The speaker pointed out the interesting case of a carriage bolt die that was formed partially by hot work and partially by cold work. When hardened in this condition poor service resulted but when hardened after removal of the cold worked metal by machining, satisfactory results were secured.

Hardening—In hardening, strains are often multiplied. A large number of tools fail due to nonuniformity of heating. During heating through the critical range there is a contraction of the steel instead of an expansion, while during cooling a reverse condition is taking place[1]. If in heating a 3-inch cube, for example, conditions are not uniform, the corners of the block may expand while the central portion is contracting with the result that the corners may fly off at the first disturbance of the unbalanced stress conditions. Hardening cracks are always found following surfaces of equal temperature (isotherms).

Several very interesting color photographs of a steel block and of a pyrometer in its protecting tube, placed closely, side by side, as they appeared in a furnace with uniform rate of heat application, at 1325, 1355, 1400 and 1425 degress Fahr. (715 ,735, 760 and 775 degrees Cent. respectively), were shown. At 1325 degrees Fahr. (715 degrees Cent.) the two objects are of the some color. The block appears somewhat darker than the pyrometer protecting tube at the critical temperature owing to the heat absorption of the block, while when this critical temperature is exceeded the color of the block gradually approaches that of the tube so that when 1425 degrees Fahr. (775 degrees Cent.) is reached, both again appear of the same brightness. The heat distribution at the critical temperature and slightly above is far from being uniform and this stage is a dangerous one for finishing the heat treatment, because of the great strains which would be set up by quenching under such conditions.

Thus, the pyrometer has its limitations and hardening is a heating operation controlled by the eye to a certain extent. During the hardening, soft spots may be produced. They may be due to a number of causes; surface decarburization, contact with tongs by which the article is held during the immersion in the quenching medium, dirt present in the quenching solution; in general anything which interferes with rapid quenching may produce soft spots. The use of a 10 per cent brine solution may prevent the formation of soft spots in many cases. It must be kept in mind that hard steel occupies a larger volume than soft steel, so the soft spots are usually under severe compression stresses. These often amount to 100,000 lbs. per sq. inch.

The speaker recommended the following method of hardening straight carbon or low alloy steels; quench in water to about 700-800 degrees Fahr. (371-427 degrees Cent.), then into oil until nearly cold and finally cool in air.

Tempering—The time elements was emphasized by the speaker as a

[1]For illustrations, Bureau of Standards temperature expansion diagram was cited. See Bureau of Standards Scientific Paper No. 433, 1922, by W. Souder and P. Hidnert, p. 618.

very important feature[2] in obtaining complete release of internal stresses in this operation, and often greater hardness.

Grinding—Two types of defects were pointed out: (1) grinding checks of almost microscopic size and (2) deep seated grinding cracks. The speaker believes that grinding cracks are nothing more than delayed hardening cracks whereas the former result from poor grinding practice or accidental mistreatment in grinding. A number of slides of steel tools etched in hydrochloric acid to make these defects visible were shown. An interesting case was cited in which the steel was highly heated locally as a result of careless grinding and a soft spot was produced.

In conclusion the speaker pleaded for a greater co-operation between steel makers and steel users.

During the discussion following this brilliant talk it developed that:

(1) Some badly flaked high-speed steels (fish type of fracture) show under the microsope very large polygonal grains.

(2) Annealing at 1650-1700 degrees Fahr. (895-930 degrees Cent.) between high temperature heatings usually prevents formation of the fish scale fracture.

(3) High tugsten (18 per cent) steel is not as prone to the formation of "fish scale fracture" as low tungsten (13 per cent) steel, but once this type of fracture is produced it is much harder to eliminate in high tungsten steel than in low tungsten steel.

(4) If carbon or low-alloy tool steel is heated to a temperature above 1300 degrees Fahr., cooled then to room temperature, reheated to above the critical temperature and quenched, quenching cracks are usually absent while if this steel is subjected only to the second treatment cracks occur rather often.

(5) The effect of punching holes in producing stress was illustrated in the case of plate steel of 80,000 pounds per square inch tensile strength, by the relative strength of 1 x 4 inch strips with a single row of $1\frac{3}{16}$ inch holes, in one case neat punched and reamed, and in the other case drilled:

$$\frac{\text{drilled}}{\text{punched}} = \frac{240000}{197000}$$

(6) It is doubtful if the process of nitration developed by Dr. Fry and carried out at a temperature not exceeding 1025 degrees Fahr. (550 degrees Cent.) may be applied, at least at the present time to the manufacture of steel tools because of the extreme brittleness of the case. The case due to this process chips off easily during the Rockwell hardness test. For some kinds of service, however, it gives better results than the usual case carburizing process. It was pointed out that chromium plating is also advantageous for some surface-hardened parts.

A rising vote of thanks was accorded to the speaker.

A. I. Krynitsky.

[2]This was illustrated by the temperature-expansion diagram taken from the Bureau of Standards Scientific Paper No. 344, 1922, by W. Souder and P. Hidnert, p. 624.

CORRELATION OF MAGNETIC PROPORTIES WITH MECHANICAL HARDNESS IN COLD-WORKED METALS—Part II—Nickel Strips

(Continued from Page 898)

if the grain size, or the chemical composition, or the method of preparation of the sample is changed, the magnetic results no longer stay on the calibration curve and they may be seriously misleading. I think that is the rock upon which most magnetic testing so far proposed has been wrecked. It has been tried a great many times because it looked so simple, and it has failed almost an equal number of times because conditions arose which did not recognizably change the mechanical properties but which did change the magnetic properties. The problem can be worked out, but it is not at all the simple thing that it looks to be when first approached.

P. G. McVETTY: It is indeed interesting to find further evidence of a relation between Brinell hardness and the results of the magnetic test. Mr. Lessells showed us on Monday that a similar relation exists between Brinell hardness and ultimate strength providing that the material is homogeneous and without residual stresses. We have been using a similar comparison of hardness and magnetic properties as a basis for choosing uniform test specimens for long-time tensile tests at high temperatures.

Some time ago we tested some supposedly uniform heat treated material and found wide variations in the test data. Investigation showed that this might result from slight changes in tempering temperatures. Before discarding a large number of finished pieces, Mr. Spooner suggested that tests for uniformity be made. These tests showed a variation in permeability of about 25 per cent. Tensile tests of the two pieces having the greatest difference in permeability showed a difference in ultimate strengths of more than 20 per cent, which is in close agreement with predictions based on the magnetic tests. As our investigation required uniform test specimens, these pieces were discarded.

In many cases the variations in test specimens of heat treated material are shown by making several tests under similar conditions. It is practically impossible to obtain such statistical data for long-time tests at elevated temperatures on account of the time and equipment necessary for each test. It is therefore imperative that every possible effort be made to provide uniform test specimens.

Our present practice is to follow carefully the heat treatment of the original bars by means of Brinell tests. After the selected specimens are machined, magnetic tests are used as a basis for a second selection. By making tensile tests of the pieces showing the greatest variation in magnetic and Brinell values, we determine the corresponding variations in tensile properties, after which specimens of the desired degree of uniformity may be chosen.

This method is still in a state of development but it appears to furnish a valuable means of selecting uniform test specimens. The success of this method depends upon the existence of definite relations among the hardness, tensile and magnetic properties of the material. Professor Williams has made a valuable contribution toward establishing this relationship and it is hoped that work of this kind will be continued.

Items of Interest

ANNOUNCEMENT is just made of the purchase by the Simonds Saw and Steel Company of Fitchburg, Massachusetts, of the plants and business of the Abrasive Company of Philadelphia, Pa. The Abrasive Company is one of the leading companies in the grinding wheel manufacturing field, making "Borolon" wheels for grinding steel and metals of high tensile strength, and also "Electrolon" wheels for grinding cast iron, brass, bronze, and metals of low tensile strength. It also manufactures abrasive cloths and papers. The company has a complete organization of branches and sales outlets and will continue to sell its wheels through the same channels as in the past. The Simonds Company, established in 1832, is one of the oldest and largest manufacturers of saws, files and machine knives, owning and operating their own steel mill, in which, in addition to making steel for their own products, they make sheet and bar steel for the commercial market.

The products of both the Simonds Saw and Steel Company and the Abrasive Company are used almost entirely in the industrial woodworking and metal working field, and this close association of the two companies should not only prove mutually beneficial to them but also acceptable and useful to the consumers of both the Simonds Company's products and the Abrasive Company's wheels.

"Taking the 'Mystery' out of the Buying of Automotive Oils" is the title of a handbook published by D. A. Stuart & Company of Chicago. It is especially of benefit to purchasing agents, plant engineers, and users of Stuart Technical oils. Sent upon request.

Ludlum Steel Company announces that its Boston Office is now located in the Statler Office Building.

More than fifty years ago, when testing was rather a new idea, A. H. Emery designed and built a testing machine for the War Department. It was installed in the year 1875 at the Watertown Arsenal and has been in use ever since. Upon the completion of this machine, a series of studies and experiments on physical testing devices was begun which culminated in the splendid examples of precision machinery now being used at the Bureau of Standards.

A. E. Donovan, former secretary and treasurer of the Philadelphia Chapter is now in New York City. He is connected with the Crucible Steel Company of America, 17 East 42nd Street.

A review of the work, completed and in progress, relative to the determination of the properties of metals at elevated temperatures is to be given by A. E. White, Director of Engineering Research of the University of Michigan, in behalf of the American Society for Testing Materials, at

a meeting of the International Congress for Testing Materials to be held in Amsterdam, September 12th to 17th.

The rapid growth of the iron industry in the Netherlands during the past three years is revealed in a trade bulletin issued recently by the Iron and Steel Division of the Commerce Department.

Although official figures are lacking, it is estimated that during the fiscal year which ended in March, 1927, Dutch blast furnaces produced in the neighborhood of 200,000 metric tons of pig iron. While this figure is relatively small, it is striking in view of the fact that prior to 1924 the iron industry in the Netherlands was non-existent.

The decision of the Dutch to establish an iron industry of their own, according to the bulletin, came about as a result of the rigid supervision exercised by the belligerent countries during the war over iron and steel exports. The Royal Dutch Blast Furnaces and Steel Works, known to the trade as "Hoogovens," was organized in 1918 with a capital of 25,000,000 florins of which the Dutch government participated to the extent of 7,500,000 florins. A plant was built near Amsterdam which began operations in 1924. During the fiscal year 1924-25 Dutch plants produced 106,000 metric tons of pig iron which was increased to 109,000 the following year. A second blast furnace was blown in on January 8, 1926, after which production increased markedly. The total capacity of the plant is over 235,000 metric tons per annum.

The iron ore used in the Dutch plant, the bulletin disclosed, comes from Sweden, France, Spain and Algiers, long-term contracts having been made with mines in all four of these countries. For its coal the Dutch company has a source of supply in the Limberg mines and it also has acquired control of several German mines which assure sufficient coal for many years to come. The limestone used comes from Belgium where the Dutch own an important pit.

The importance of the Dutch iron industry in world trade, the bulletin points out, is out of proportion to the actual production of the Dutch plants, owing to the fact that practically the entire output of pig iron is exported. The United States is by far the largest buyer of Dutch pig iron. In 1925 out of 95,000 tons exported, 52,000 tons were shipped to this country, while during the first ten months of 1926 out of total exports of 92,000 tons, 57,000 tons represented exports to the United States. Italy, Switzerland, Denmark, and Sweden also take considerable quantities of Dutch pig iron.

Technologic paper No. 335 of the Bureau of Standards on "Thermal Expansion of Graphite", by Peter Hidnert and W. T. Sweeney has been issued. This gives the results of an investigaton on the thermal expansion of longitudinal and transverse sections of artificial graphite electrodes over various temperature ranges between room temperature and 1112 degrees Fahr. (600 degrees Cent.) A summary of available data by previous observers on the thermal expansion of graphite (natural and artificial) and of other forms of carbon is also included.

"Pyrometer Instruction" is the title of Bulletin No. 358 recently published by The Bristol Company, Waterbury, Connecticut. The information

contained in the bulletin is intended as a guide to users of Bristol's Thermo-Electric Pyrometers, in securing the greatest efficiency and satisfaction. Information concerning this and other details pertaining to the use of these instruments may be had at any branch office. Sales engineers are available for consultation, and service engineers for repairs and checking. The main laboratory is at Waterbury, Connecticut, and service stations are located in Chicago and Toronto.

Claude S. Gordon Company, Chicago, announces the opening of a new branch office in Indianapolis to better serve their clientele in that territory. S. A. Silbermann will manage the new branch located in Suite 617 Merchants Bank Building, Indianapolis.

Michigan State College is endeavoring to meet a new demand in the engineering profession by establishing a curriculum in industrial metallurgy, that field of metallurgy which emphasizes the uses of metals and alloys rather than the production of them.

The automotive, aeronautic, steel and allied industries are particularly in need of men who are well trained in industrial metallurgy. There is a scarcity of men who can correlate mechanical engineering, especially advanced design, with the science of metals and are indispensable to these industries.

The proposed course in industrial metallurgy was developed after considerable study of the demands of the industries upon metallurgists. Comparisons were made between the demand and the various metallurgy curricula offered throughout the country and no curriculum seemed to offer the necessary combination of mechanical engineering and the science of metals.

Michigan State College is uniquely located to offer such a training in metallurgy. It is in the center of the automotive industry of which there are large representative establishments located within five miles of the campus and which afford plenty of opportunity for intimate study by the students.

The facilities afforded to the students are very complete in every line of metallurgical study and research. The equipment to accomplish this work is exceptionally good and includes in the foundry:—a 24-inch cupola and a 14-inch cupola, 2 gas-fired crucible furnaces and an electric furnace of 250 pounds of steel per hour melting capacity is being installed. The metallurgy laboratory is equipped with: 9 gas-fired hearth furnaces, one 13 K W electric furnace, and 6 pot furnaces, also forges, 3 standard methods for hardness testing, and the potentiometer system of pyrometry as accessories for the metallurgy laboratory; a well equipped metallography laboratory for inspecting and photographing macroscopic and microscopic work and for making critical point determinations.

An effort is being made to have the industries cooperate with the college in the training of metallurgists. The industries are being asked to employ the metallurgy students during their vacation months in interesting, instructive and representative metallurgical work. It is the hope of the college that such employment of students would arouse their interest in metallurgical engineering, but it would also serve to weed out the individual who has no aptitude for the work.

(Continued on Page 36 Adv. Sec.)

JUN 10 1927

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JUN 10 1927

Transactions of American Society for Steel Treating

Vol. XI June, 1927 No. 6

FEATURES

Comparison of the Alloying Elements Chromium, Nickel, Molybdenum and Vanadium in Structural Steels—*H. J. French* 845

Correlation of Magnetic Properties with Mechanical Hardness in Cold-Worked Metals—Part II—Nickel Strips—*S. R. Williams* 885

Fundamental Research in Steel Manufacture—*C. H. Herty, Jr.* 899

Centrifugal Casting of Steel—*Leon Cammen* 915

The Decomposition of the Austenitic Structure in Steels—Part V—*Oscar E. Harder and Ralph L. Dowdell* 959

The Automatic Electric Furnace—Its Uses and Possibilities—*Harold F. Wood* 975

The Constitution of Steel and Cast Iron—Part IX—*F. T. Sisco* 986

Pouring "pigs" at our new blast furnace—the most modern in America

Here Progress in Steel Manufacture Parallels Progress in Metallurgical Science

FOR many years our laboratories have been famed for their contributions to the art of metallurgy. And our mills, too, have an enviable reputation for the modern methods and equipment employed in making Agathon Alloy Steels. In addition, every employee is imbued with the spirit of painstaking care in every step of production. Such a combination of skill, up-to-date equipment and modern methods is bound to result in alloy steels that adhere strictly to formula and are absolutely uniform in texture, providing substantial savings in subsequent operations. Have you a copy of our Agathon Alloy Steel handbook?

We have daily production in our two completely equipped plants at Massillon and Canton in all kinds of Agathon Alloy Steels, such as:

Nickel, Chrome-Nickel, UMA, Molybdenum, Chrome-Molybdenum, Nickel-Molybdenum, Vanadium, Chrome-Vanadium, Chromium, etc.

Deliveries in Blooms, Billets, Slabs, Hot Rolled, Heat Treated, and Cold Drawn Bars, Hot Rolled Strips, etc.

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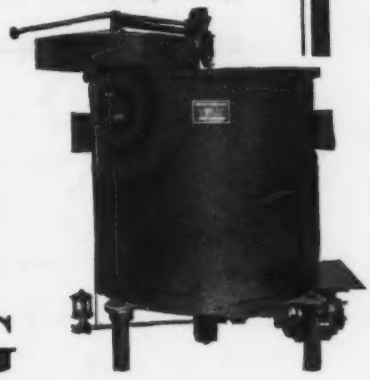
Our engineers can show you how to reduce costs and improve results in heat treating steel. Our literature will inform you of the latest developments in the heat treating equipment field.



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are standard factory parts on many of the best cars in the various price classes.

The Resistance of ASCOLOY to corrosion and abrasion makes carbon steel obsolete as a suitable material for this vital part of the car.

The Cost of using ASCOLOY is surprisingly moderate.

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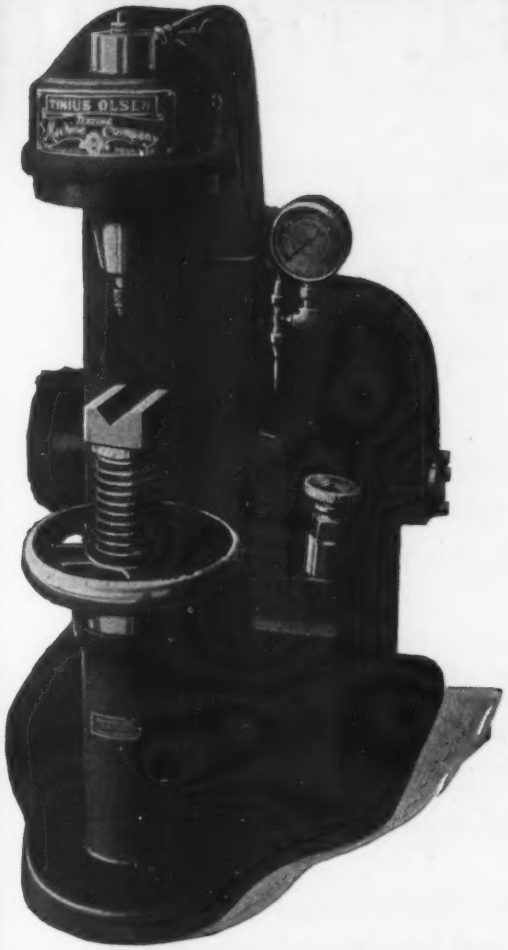

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Olsen Motor Driven Production Type Brinell Hardness Testing Machine

Machine as here illustrated is the very last word in Brinell Hardness Testing Equipment, and which enables the operator to make Brinell Hardness Tests on a real productive basis.

This Machine is made in several sizes, depending upon the class of work to be Brinelled and is supplied complete with a Special Illuminated Microscope.

The entire control of the machine is by operating the small knurled head at the right through a very small angle for either applying the load or removing same, while the load is automatically held at maximum point over such a length of time as desired by the operator.

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HEART TO HEART TALK WITH STEEL TREATERS

By the President of

E. F. HOUGHTON & CO.

THIS space costs good money. The fact that the money goes to a good cause does not reduce the cost. I am expected to use words and have them printed on this space which will bring back most all, or part.

As practically every member of the Society knows all about Houghton's Carburizers and most of the casehardeners are using them, it looks like a waste of space to keep harping on Houghton's Carburizers. I suppose I touch on some other Houghton Products.

HOUGHTON'S No. 2 Soluble Quenching Oil is in a class by itself and is even better known than the Houghton Carburizers.

The fact that Houghton does a very extensive business upon salts for liquid baths employed in the heat treatment of steel is perhaps not quite so well known, but the story is told so much better than I can tell it in a book entitled "HOUGHTON'S LIQUID BATHS FOR THE HEAT TREATMENT OF STEEL" edited by the Houghton Research Staff and published by the Company, that it would also be a waste of space to try to tell that story here. Besides, and this is strictly confidential, that story is a little over my head, and I am not so certain that I have the ability to do justice to it. But for Heaven's sake don't tell, for I pull down a whale of a salary because I am supposed to possess the ability to write all about all of the Houghton Products, so that men will fight for them, women will scream for them and children cry for them, and if our Board of Directors heard that this were not true I

ight reduce my salary and I am getting well along in life and I need
e money. Of course, no one knows what I don't know but myself and
am not going to tell what I don't know. It is some job to tell all
e knows after being connected with Houghton for 45 years.

ou may obtain a copy of the book LIQUID BATHS for the asking.

here is one phase of our business that I do claim to know fairly well
d that is LUBRICATION AND LUBRICANTS. I like it so much
t sometimes I suspect there is Spanish or Mexican blood in my veins,
r there is so much "bull" in it and I love to kill the "bull," and I
spect that I like to tease it a bit also.

lush to admit it, but I also claim to be an inventor. I am an inventor
phrases. I invented the phrase "Bootleg Motor Oil." At first folks
d not pay much attention to it. Of late it has been the subject of
ding articles in many of our periodicals of largest circulation.

hensoever you become sufficiently intelligent to believe that the lubri-
ion of your car is as important as the lubrication of your plant, send
a Houghton Man and have a talk with him about HOUGHTON'S
TAL MOTOR OIL. I will wager that in years to come you will
mit it was the most profitable half hour you ever spent.

ave threatened to write a book on the subject of motor lubrication.
I do, it will be a peach. I admit it. Some folks may not like it,
the "Bootleg Motor Oil" business will receive a jolt.

ope this finds you in a good humor and that the weather is pleasant
your way.

d I repeat, I draw a good salary for writing this sort of copy, which
s to show it is easy to make a living, if you do not insist on doing
ything as it has always been done.

Yours fraternally,

CHAS. E. CARPENTER,
President.

No. 3 Regular Melter

Melting Furnaces

SMALL and medium size melting furnaces are fundamentally plain, sturdy furnaces designed to withstand hard service and high temperatures.

Standard melting furnaces, one of the many types of heating equipment supplied by the American Gas Furnace Company, are shown in their new Bulletin No. 5. In them is incorporated the many years' experience which they have had in the manufacture of this line of equipment.

Heavy, highest grade refractory lining and ample burner capacity result in rapid, efficient melting.

Regular melters for melting precious and semi-precious metals and for making small experimental melts, melters for making fusion test on coal ash, etc., brass melters and special melters are all described and illustrated in Bulletin No. 5.

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Are you suspicious of flame-cut steel?*

THE REAL ECONOMY of cutting steel with the oxy-acetylene flame is well established. A three pound blowpipe replaces massive machinery. Even in shops that have installed such machinery the odd jobs and emergency jobs are more quickly accomplished by the oxy-acetylene process. It eliminates the delay of routing heavy pieces back to the shears.

Nevertheless there is a groundless suspicion that the heat of the flame has damaged the steel. Some engineers even insist on machining ¼" to 1" of metal from the flame-cut edges.

Now it is a fact established by several different engineering investigations that mild steel and structural steel are actually stronger after they have been flame cut. Bars taken from the flame-cut edge show a bending strength of 5%-10% higher than those from a milled edge. A slight hardening takes place ⅛" to 3/16" inward from the surface.

Linde Engineers can supply you with convincing metallurgical data on the various applications of the oxy-acetylene process.

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* No. 6 of a series of advertisements on the engineering phases of oxy-acetylene welding and cutting. Send for the booklet entitled: "Engineering and Management Phases of Oxwelded Construction."

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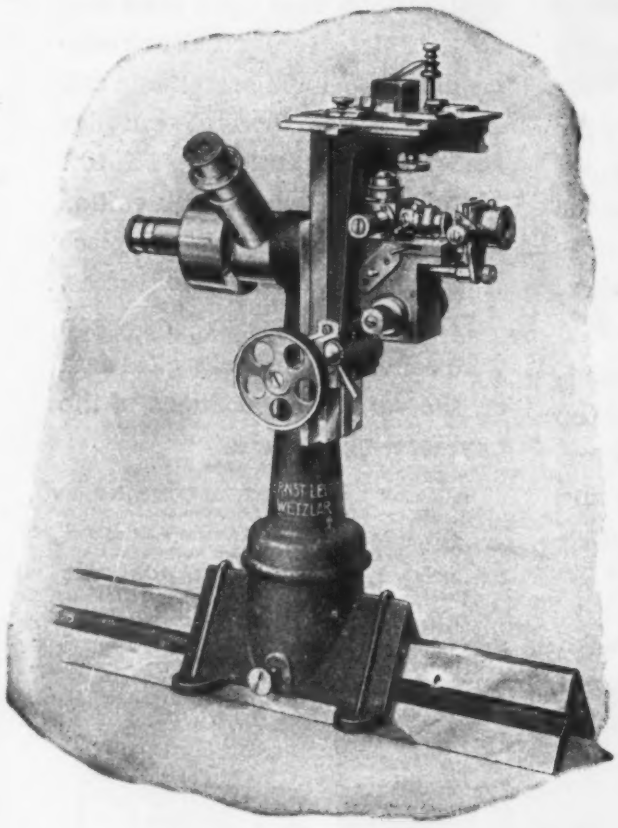

Inverted Microscope Stand of Leitz Micro-Metallograph

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8. It polishes specimens optically plano;
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10. It is likewise adapted to polish ends of fine wire in an entirely satisfactory manner;

Saving of Labor:

1. Labor is reduced to a mere minimum;
2. **Three** specimens can be prepared at one time, in the same time as **one** formerly;
3. The machine pays for itself in no time through the labor saved.

Automatic Dropping and Agitation Device:

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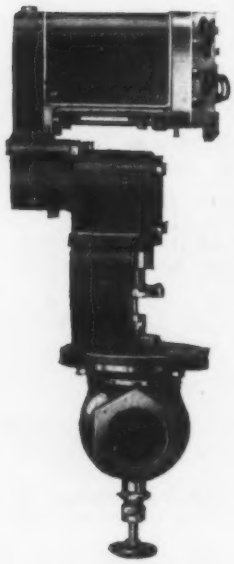

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TEMPERATURE CONTROL SAVES THOUSANDS OF DOLLARS YEARLY

THE "allowance for spoilage," common in many heat-treating processes, can often be charged to incomplete control of process temperatures.

Bristol's Pyrometer Control Reduces "Spoilage"

Much of this spoiled material can be prevented by installation of automatic control. The Bristol's model 479 controller shown here, when used in conjunction with Bristol's Motor Operated Controller Valves will hold the "run of heat" to almost unbelievably close control for use on oil, gas and electrically fired equipment.

Extremely sensitive, yet rugged, and designed to give years of service with little care.

Bristol Service Engineers analyze conditions carefully, and can specify just the right equipment to do the work.

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ELECTROMET supplies zirconium as zirconium-ferrosilicon and as silicon-zirconium. Our engineers will be glad to consult with you on the use of these interesting alloys.

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Die accuracy means that the high heat-resisting properties of "Nichrome" are greatly increased at every point by uniform wall thickness and by greater density of the metal itself. "Nichrome" tubes are tested under water at 100 pound air-pressure for your protection.

Your instrument maker carries "Nichrome" Pyrometer Protection tubes in stock made only by the

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ROCKWELL HARDNESS TESTERS

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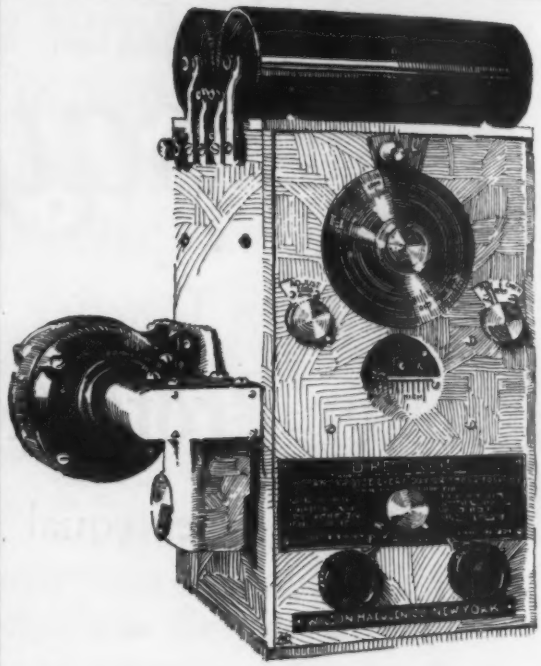

THE dial of this Automatic Temperature Controller on which you set the temperature for furnace operation is 12″ long, the length of the scale surrounding this illustration.

The electrical system is potentiometric with complete electrical cold-junction compensation.

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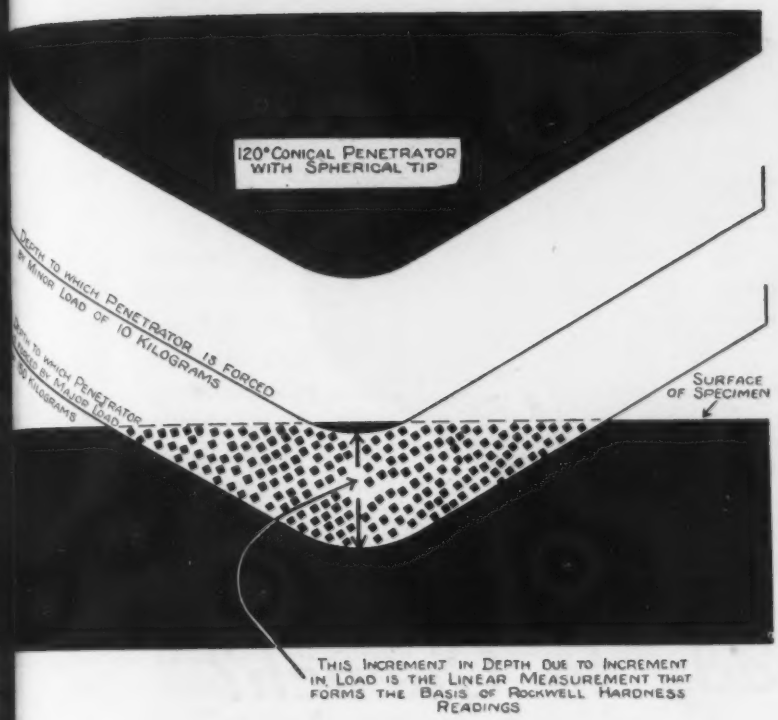
AT TREATMENT OF STEEL

PYROMETERS


120° Conical Penetrator with Spherical Tip
Depth to which Penetrator is forced by Minor Load of 10 Kilograms
Surface of Specimen
This Increment in Depth Due to Increment in Load is the Linear Measurement that forms the Basis of Rockwell Hardness Readings

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RECORDING

AUTOMATIC CONTROLLING

LOW HIGH

ONE reason that the Rockwell Hardness Tester is so largely independent of character of surface of part tested is that the total depth of penetration is disregarded:—the hardness number being based upon the *increment* of depth of penetration due to *increment* of load. The Rockwell is never concerned with the first contact of penetrator and piece tested.

The diagram above illustrates this principle of the Rockwell Test.

NEW YORK

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LOOK through a Pyro Radiation Pyrometer at the steel you're treating while it is in the furnace. Read the temperature on the scale. That's the temperature of the work—not merely that of the furnace.

More than 4,000 Pyros in use throughout the world. A list of users reads like "Who's Who in Industry."

Pyro helps increase furnace output, promote uniformity of product, reduce spoilage and save fuel.

No accessories needed. Weighs 25 ounces, 7 inches long —demonstrated accuracy.

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100 YEARS OF STEEL IMPROVEMENT

Number Three in a Series of Advertisements

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In July 1853, Crystal Palace was formally opened by President Franklin Pierce, who came from Washington for the event. Among the many artistic and scientific exhibits that aroused the interest of the curious throngs were samples of Philip Thurber's Nickel Alloy Steels. The American public thus received its first glimpse of those Alloys that had been the subject of many far-reaching European experiments—its first glimpse of Nickel Alloy Steels which are now accepted as standard materials of industry.

The many years of Nickel Steel development have contributed to an extensive fund of information concerning the superior properties and many uses of these Alloys. You are invited to consult our staff of engineers and thus draw upon these helpful data.

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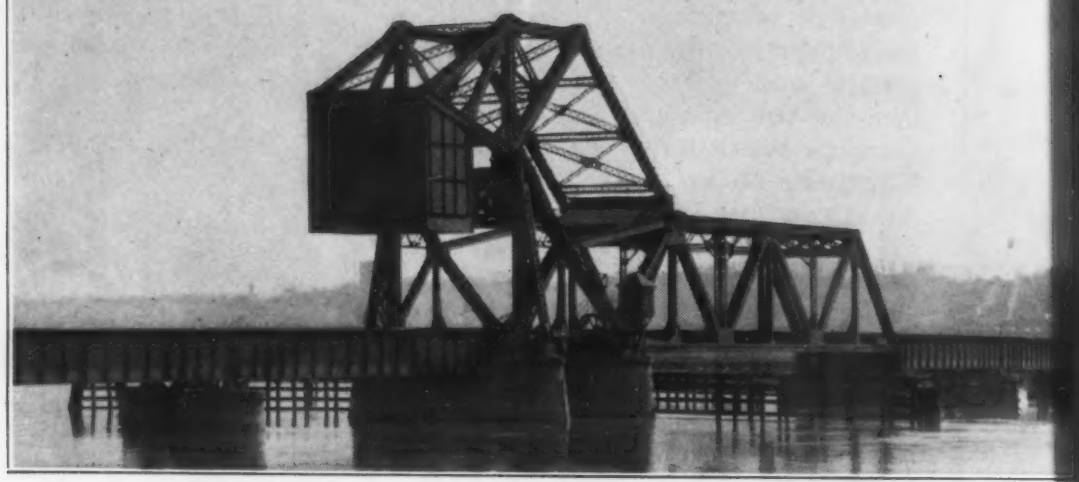

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Note: No pictures are now available of the bridge in the Philippines. bridge above is in the United States. Recent report after two one-half years' protection by NO-OX-ID stated that it was in fect shape and would need no more attention for about three y

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Norman Conn & Company, metallurgists and heat treaters, have recently opened offices at 2435 Merrick Avenue, Detroit, Michigan.

Development of a limited iron and steel industry in certain western localities where, under present economic conditions, such operations are not commercially feasible, is suggested as the result of experimental work in the production of sponge iron performed by the United States Bureau of Mines, Department of Commerce, at its Seattle station. Sponge iron also promises to become of great economic importance in the leaching and precipitation of copper and lead ores.

Sponge iron is the product formed by the reduction of iron oxide to metallic iron at a temperature below the fusion point of the constituents of the charge. A particle of sponge iron has the same size and shape as the particle of ore from which it was reduced, but because of the removal of the oxygen from the oxide it is much more porous. By reason of this porosity of sponge iron it reacts more vigorously and rapidly than the ordinary massive forms of iron. Under suitable reducing conditions sponge iron can be produced readily on a commercial scale at about 1652 degrees Fahr. (900 degrees Cent.) and can be magnetically separated from a large part of the associated impurities.

Sponge iron will precipitate copper, lead, and numerous other metals from solution. The reaction takes place quicker than when a massive form of iron, such as steel scrap or pig iron, is used as a precipitating reagent, and thus plant capacity is proportionately enlarged. Sponge iron is likely to be increasingly important in the hydrometallurgy of low-grade copper and complex lead ores; its production insures a permanent and reliable source of metallic iron, a matter of much importance in view of the small supply of scrap iron and the distances that separate most copper and lead mines from iron-producing centers. It is conceivable that the future success of some large-scale leaching and precipitating processes for copper and lead ores may depend largely upon a supply of cheap sponge iron. In some chemical processes finely divided metallic iron is used as a reducing agent, and iron oxide is obtained as a by-product. This oxide could be converted into sponge iron and used again in the reduction process.

(Continued on Page 38 Adv. Sec.)

"Brinell"

The International Standard Method *for* Testing Hardness

Fisher Brinell-Hardness Tester

(*Another Fisher Product*)

12-150

***No. 12-150 Fisher Brinell Hardness Tester.** Results in Brinell numerals, the International Hardness Standard.

FEATURES: The leveling stage makes it possible to test irregular shape pieces. A replaceable patented rubber diaphragm does away with the necessity of a ground cylinder and piston, and eliminates leakage of the hydraulic fluid.

The pressure is applied uniformly, without pulsations. Accommodates test pieces from 3/16 inch to 12 inches. Range up to 500, International Brinell Hardness Number with regular ball; with special ball, up to 700.

Simple and quick operation. **Price $350.00**

The number identifies the apparatus in the 630-page Fisher Catalogue. Has your laboratory a copy? If not, write for one.

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The possibility of making sponge iron and converting it directly into steel, thus eliminating the pig-iron stage, has been suggested from time to time, and hundreds of so-called "direct steel" processes have been proposed or tried during the past century. Unquestionably the production of steel from sponge iron has theoretical advantages over the standard methods. Moreover, the production of both steel and pig-iron from sponge iron has economic advantages in certain localities. In regions remote from iron and steel producing centers, where coke is expensive and electric energy cheap, sponge iron made cheaply from iron ore and low-grade coal can probably be converted in the electric furnace into iron and steel that can compete with the imported products. The fact that both electric melting and the production of sponge iron can be conducted economicaly on a small scale makes such a process particularly advantageous in communities that do not consume much iron or steel. Electric furnace processes, being inherently expensive, are not advocated for the manufacture of iron and steel except where conditions are unusual.

Other uses of sponge iron will probably be developed once production has been established on a large scale. Some experiments have been made with respect to the use of sponge iron for the production of hydrogen from steam—the iron oxide formed in the process to be converted to sponge iron.

Sir Robert Hadfield, honorary member of the A. S. S. T., will present before the spring meeting of the British Iron and Steel Institute a paper entitled "CO_2 Meters (Electrical)". The instrument described is said to of Ferro-Manganese and Its History".

This paper is an endeavor to give a general historical account of the metal manganese and the uses to which it has been applied. This paper is specially concerned with the use of manganese in the steel industry.

The Leeds and Northrup Company have recently issued bulletin No. 781 entitled "CO_2 Meters (Electrical)" The instrument described is said to be the result of four years of development in their research laboratories and two years of testing these instruments under service conditions.

"Comparative Tests of Six-Inch Cast-Iron Pipes of American and French Manufacture" is the title of technologic paper No. 336 by S. N. Petrenko, issued by the Bureau of Standards.

Comparative tests were made on 6-inch cast-iron pipe manufactured in France and on similar pipe manufactured in this country. The pipes were of the "bell and spigot type" and were cast in sand molds. These tests including hardness, transverse, ring, shear, impact, and hydrostatic tests have shown that the strength of the French pipe is within the range of variation of the American pipe.

The Fisher Scientific Company of Pittsburgh has issued a booklet describing the Fisher Brinell Hardness Tester and how to operate it. This may be had upon request to the Fisher Scientific Co.

(Continued on Page 40 Adv. Sec.)

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The Board of Directors of the American Foundrymen's Association, upon recommendation of the Board of Awards, has voted to award to Major Robert Alexander Bull, the Joseph S. Seaman Gold Medal of the American Foundrymen's Association, in recognition of his services to the Association and to the foundry industry.

Major Bull is a past president and honorary member of A. F. A. and has been prominently identified with the steel foundry industry. Since its organization, he has been Research Director of the Electric Steel Founder's Research Group. Major Bull is a member of many technical societies, including the A. S. S. T.

F. W. Harbord has recently been elected to the presidency of the Iron & Steel Institute of Great Britain. He has been identified with the iron and steel industry of the British Empire for forty-five years. Mr. Harbord has received the Bessemer Medal and is well known as the author of many papers and books and has taken an active part in many technical associations.

Tungsten, a treatise on its Metallurgy, Properties and Applications by Colin J. Smithells, has recently been published by D. Van Nostrand Company. The contents are as follows: Preparations of Tungstic Oxide, Purification of Tungstic Oxide, Reduction of Tungstic Oxide, Manufacture of Ductile Tungsten, Metallography of Tungsten I, Metallography of Tungsten II, Properties of Tungsten, Industrial Applications, Determination of Impurities.

Francis F. Lucas of the Bell Telephone Research Laboratories, member of A. S. S. T. and Howe medalist for 1924, has recently been awarded the medal of the Royal Photographic Society of Great Britain for 1926. This award was made in recognition of the paper contributed by Mr. Lucas during the deliberations of that society last year.

The subject treated by Mr. Lucas was a metallographic study of Hadfield manganese steel.

R. E. Bissell, metallurgical engineer in charge of research and metallurgical control of the Thompson Products Co., Cleveland, and member of the Cleveland Chapter of the Society has recently been awarded associate membership in the Royal Aeronautical Society of Great Britain in recognition of his engineering achievement in the development of airplane engine valves.

The valves used in Capt. Lindbergh's Wright "Whirlwind" engine were of the salt filled type developed by Mr. Bissell.

"Heat-Resisting" Steels is the title of a paper by Dr. W. H. Hatfield to be presented before the spring meeting of the British Iron and Steel Institute. The investigation described was carried on with a view of assisting in the production of better heat-resisting steels and also to find fundamental data concerning the nature of the attack from which steel suffers when exposed to the atmosphere and industrial gases at high temperatures.

The George J. Hagan Company announces the following district offices—20 East Jackson Blvd., Chicago, 155 West Congress St., Detroit.

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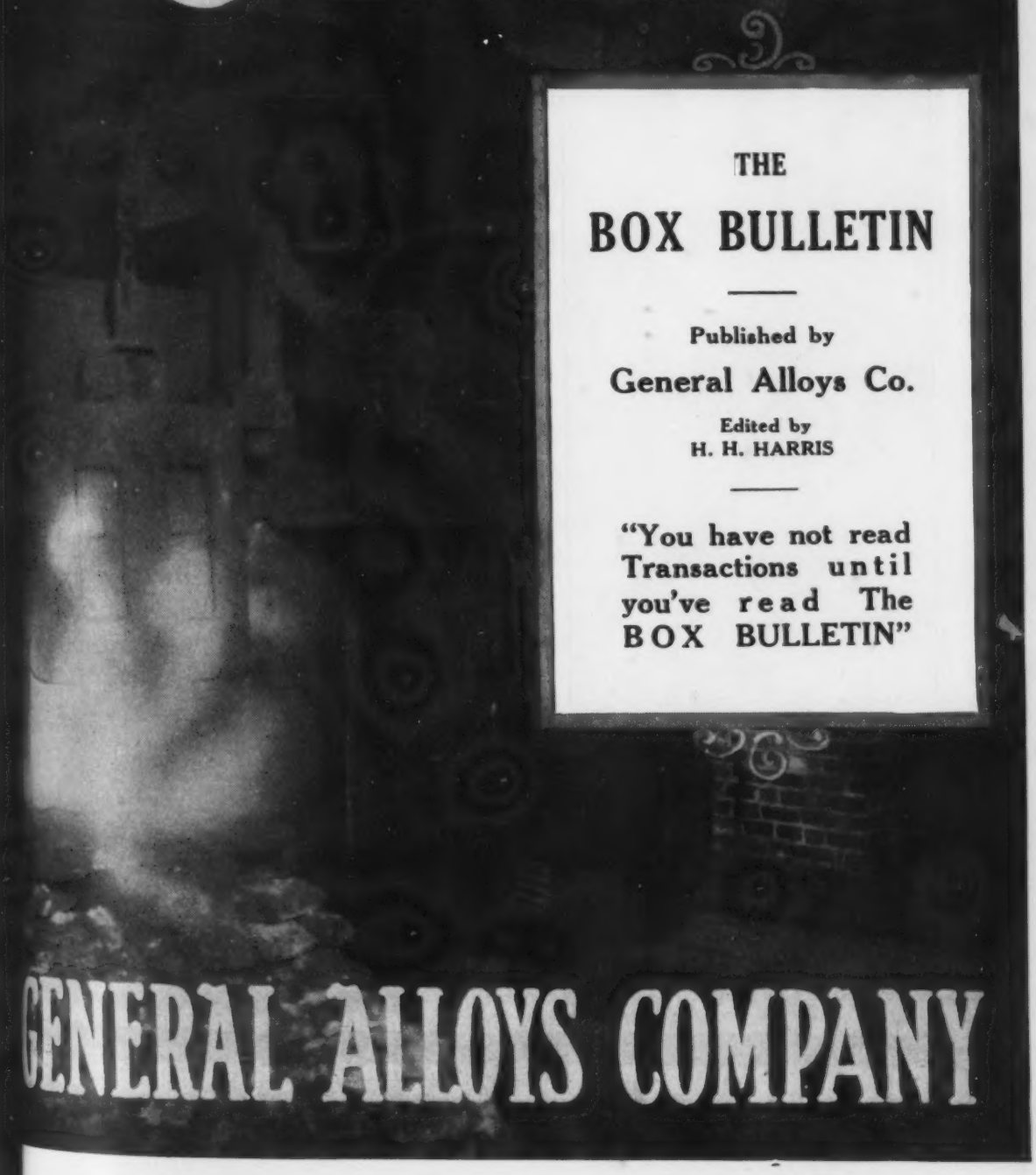
STAND UP UNDER FIRE



THE
BOX BULLETIN

Published by
General Alloys Co.

Edited by
H. H. HARRIS

"You have not read Transactions until you've read The BOX BULLETIN"

GENERAL ALLOYS COMPANY

IN MEMORIAM

LAWRENCE JOSEPH MCCARTY

Born May 28, 1892 — Died May 9, 1927

Well, Mac old scout, at sometime soon or late, death must come to us all. You had an active, busy life, crowded with the good things of the world. It was short, that's true, but it must have been satisfactory.

From the day of your birth at Roxbury, Mass., until your sudden departure you scattered smiles and sunshine all along the way. You served your country well in the great conflict, you conducted yourself with dignity and won well earned commendations.

Your life was service; service to your parents; service to your friends; service to your country and service to this company. In every one of these you played the game of life vigorously, you won without boasting, you lost without rancor, and now that the contest is over, you turn to meet the great Referee, smiling and unafraid.

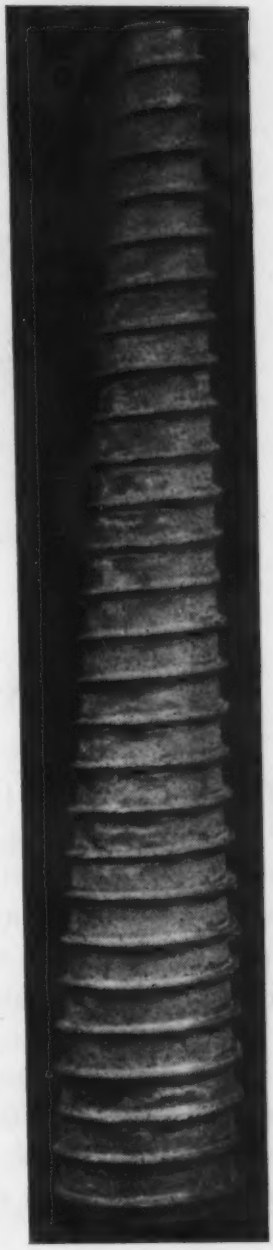
We'll miss you, Mac, we'll miss you.

When writing to General Alloys Company, please mention TRANSACTIONS

BOX BULLETIN SUPPLEMENT PAGE III

Do You Know A Good Foundryman?

IF you are acquainted with an expert steel foundryman, show him these cuts, made from untouched photos of Q-Alloy castings, and have him explain the technique he would have to follow in producing these castings SOUND, and accurate to 1/32 inch.



Q-Alloys are much more difficult to Melt, Pour, and Cast than Iron or Steel, yet our relentless search for uniform structures, and accuracy in casting Q-Alloy has developed foundry practice far in advance of the entire Steel Industry.

When you consider that all other Alloy Manufacturers are still far behind the steel foundry practice of today, you will more clearly realize the supremacy of Q-Alloys.

Such infinite care cannot be limited to the molding practice alone, but extends throughout our process, — and is reflected as well in the advanced designs, and superior engineering service, peculiar to Q-Alloys.

Uniform sections, mechanically and metallurgically sound castings resist Fatigue,—LAST LONGER. ULTIMATELY COST MUCH LESS.

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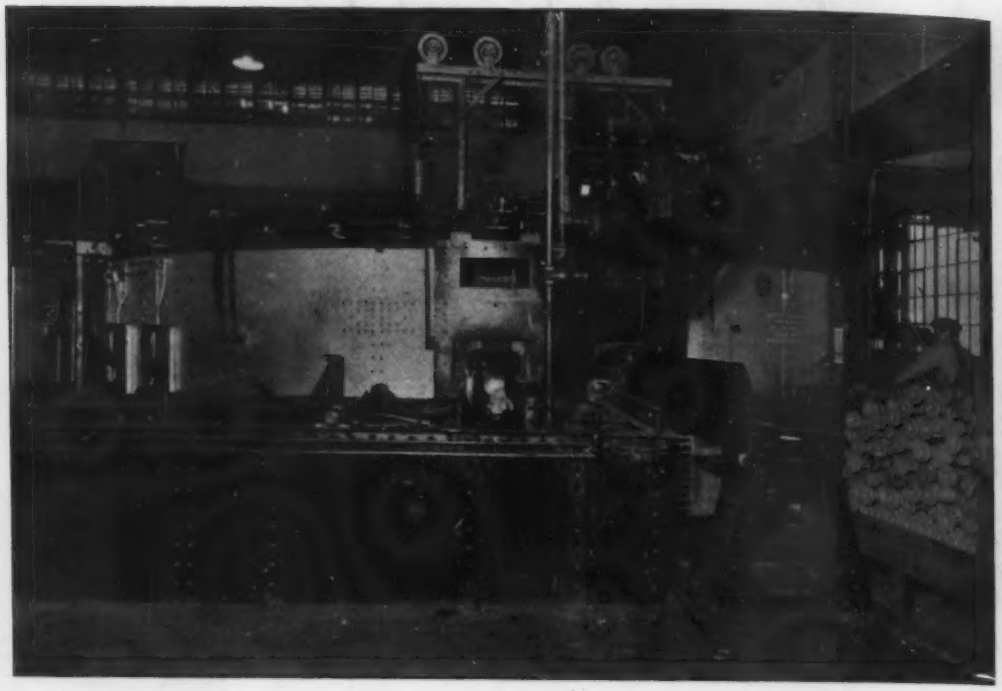


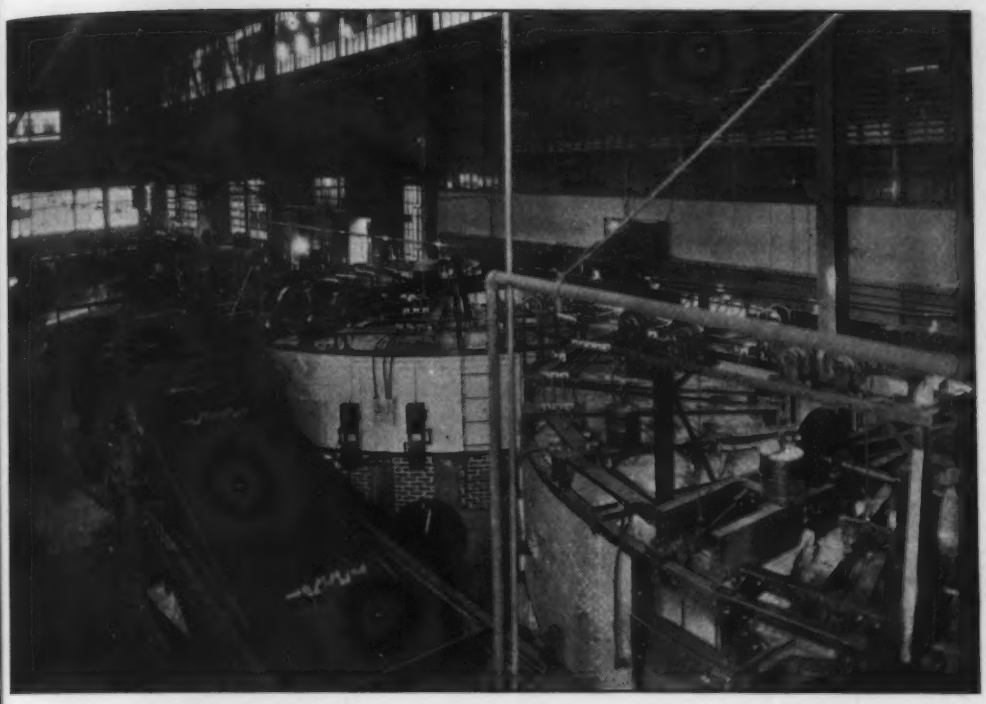
THE MERRY WHIRL

THE wheels of time and progress are forever grinding out events and improvements. Only yesterday Columbus was considered a lunatic for believing that the earth was round and that land could be found westward. You know the rest of that story. As we sit down to write our radio tells us of the success of Capt. "Lucky" Lindbergh, and in spirit we all ring his hand in congratulation on his daring feat.

The layman looks at the spectacular side of his accomplishment in wonder, but the Steel Treaters know of the effort, the endless search and research which was necessary to place in the hands of that daring pilot a mechanism capable of such wondrous performance.

In paying our tribute to the "Dauntless Aviator" let us not forget the builders of the ages who in toil and sweat and in study brought Ferrous Metallurgy and Steel Treatment to a high pinnacle of success.

Something like 4,000,000 times did the crankshaft in Lindbergh's plane turn over between New York and Paris, and this is only a part of its life!



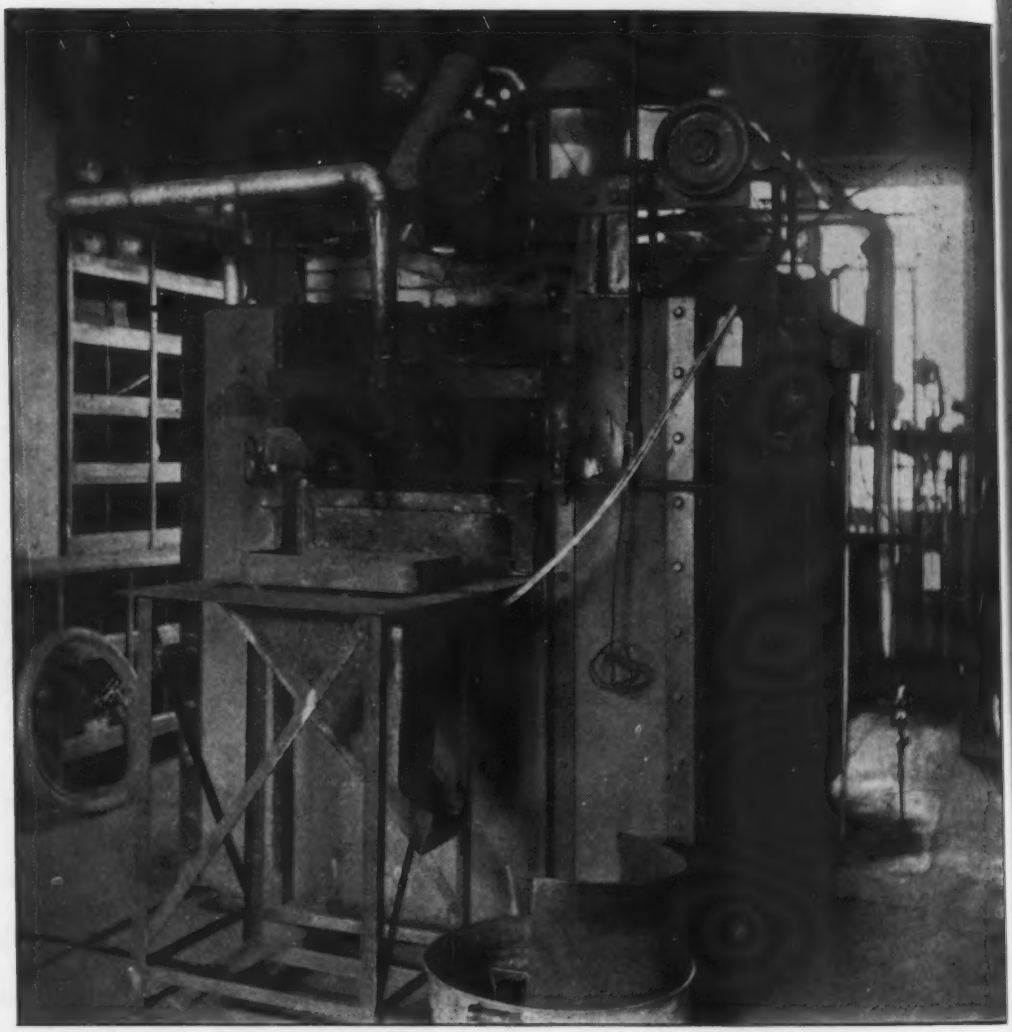
THE MERRY WHIRL

(Continued)

ND as it happens cranks are what we had in mind when we started to write.

For the last couple of years the furnaces illustrated on these pages been functioning perfectly day after day. They are installed at a modern drop forge plant in the middle west whose business is nks." The George J. Hagan Company designed and built the fur-es, and Hagan's engineers together with the engineers of their client eve in the best. That is why they placed confidence in Q-Alloys—00 lbs. go to make up the rotary sectional hearth and auxiliary ings.

After you have read the story of the success and economy of this allation, give some thought to your own Heat Treat Equipment. t Treating Machinery is rapidly supplanting the old inefficient fur-es. Remember that "A furnace is no better than its alloy parts," that "85% of the alloy parts in modern heat treating furnaces are lloys."



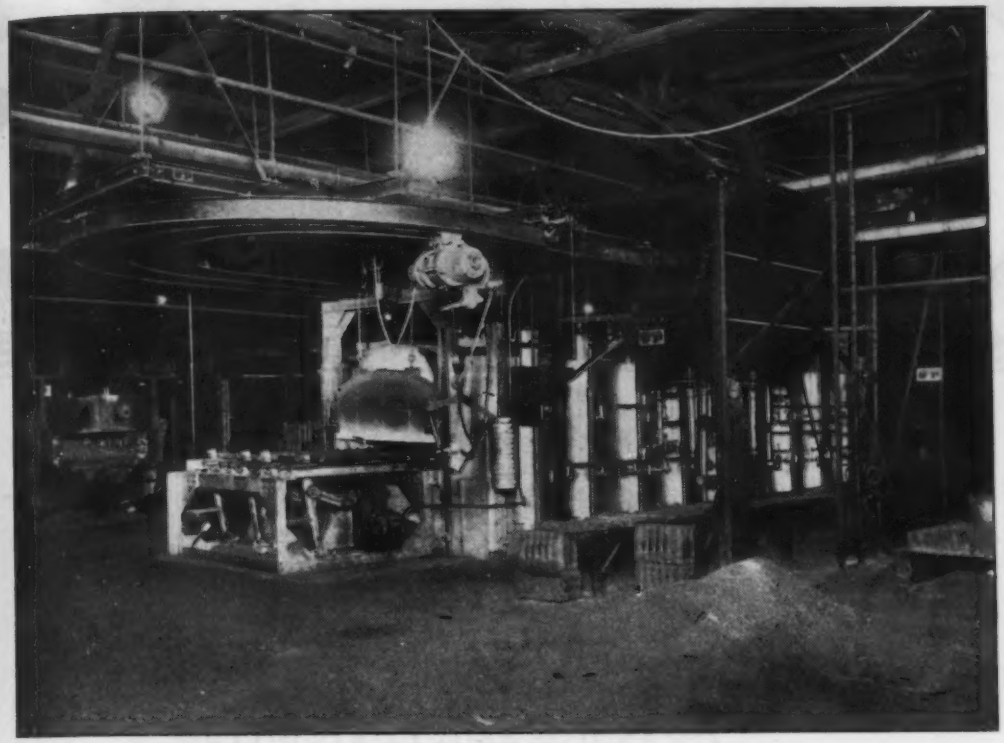
Coal Processing Research—*by Ryan*

THE F. J. Ryan & Company of Philadelphia in collaboration wi the Lehigh Coal and Navigation Company are developing equi ment for the PROCESSING OF ANTHRACITE COAL. It's a n development for which the future is good. The test furnace in the lustration is being used to work out the details of the process and i forerunner of some sizeable commercial installations.

It's a "RYAN DESIGN" from the floor up, including full automa temperature and atmosphere controls. Ryan doesn't take chances w inferior materials—that's why the hearth, trays and stack damper Q-Alloy and X-ite.

THUS Q-ALLOYS AID IN ANOTHER CONTRIBUTION T INDUSTRIAL PROGRESS.

BOX BULLETIN SUPPLEMENT PAGE VII



VESUVIUS

YEARS ago, Agricola and his colleagues used to pack their iron in a bunch of carbonaceous material* and place it alongside of Vesuvius. If Vesuvius erupted, the stuff got carbonized. Maybe they found it afterward and maybe they didn't. Anyhow Vesuvius can't be depended on.

Nowadays—not having enough volcanoes to go around—we build HEAT-TREATING MACHINES. The Surface Combustion Co. built the one in the illustration for a big automobile plant. It's a modern carburizing furnace and employs X-ite rails, rollers, rail spacers and clamps made by us. The whole unit is intelligently designed and will stand the gaff.

Production is Positively Protected.

*Animal origin.

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on the

Metallurgy of Iron and Steel

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By Bengt Kjerrman, metallurgist, Langshyttan, Sweden.
By Birger Egeberg, metallurgist, Halcomb Steel Co., Syracuse, N. Y.

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Chapter III—Manufacture of Iron and Steel Castings
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Chapter V—Chemistry of Iron and Steel
Chapter VI—Chemistry of the Blast Furnace and Bessemer Process
Chapter VII—Chemistry of the Open-Hearth and Electric Furnace Processes of Steelmaking
Chapter VIII—Chemistry of Wrought Iron and Crucible Steel
Chapter IX—Some Comments on Swedish Steel Practice
Chapter X—On Electric Steel Melting

The authors of the chapters in this book have presented the extensive subject of iron and steel manufacturing in a clear, concise manner, making their descriptions as non-technical as it is possible and still have them of scientific value.

The chapters of this book have been reprinted from the TRANSACTIONS of the American Society for Steel Treating as a result of numerous requests that they be brought together and published under a single cover.

200 pages, 6x9 **Numerous illustrations**

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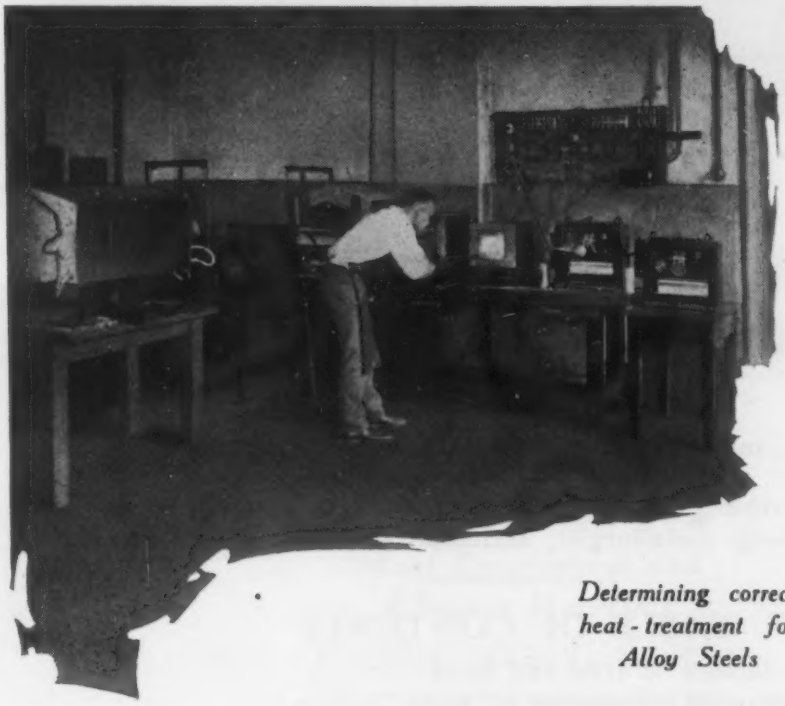

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Save 20 to 50% in first cost.
Increase life of dies enormously.
Lessen upkeep costs and fixed charges.
Increase production, with less detail and lower unit cost.

It is significant—don't you think—that nearly 4000 makers of stampings have already adopted Danly Standard Die Sets? They save in first cost, obtain precision tools, without delay or trouble of making them.

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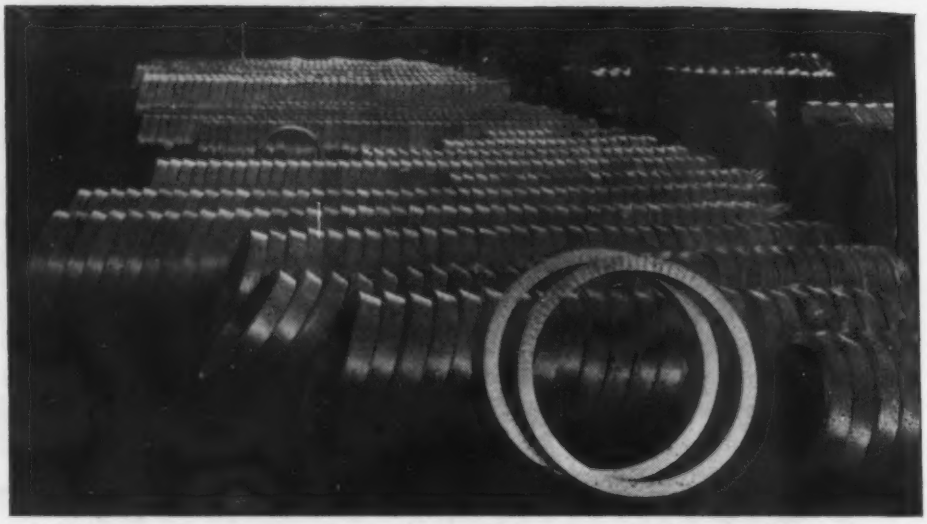

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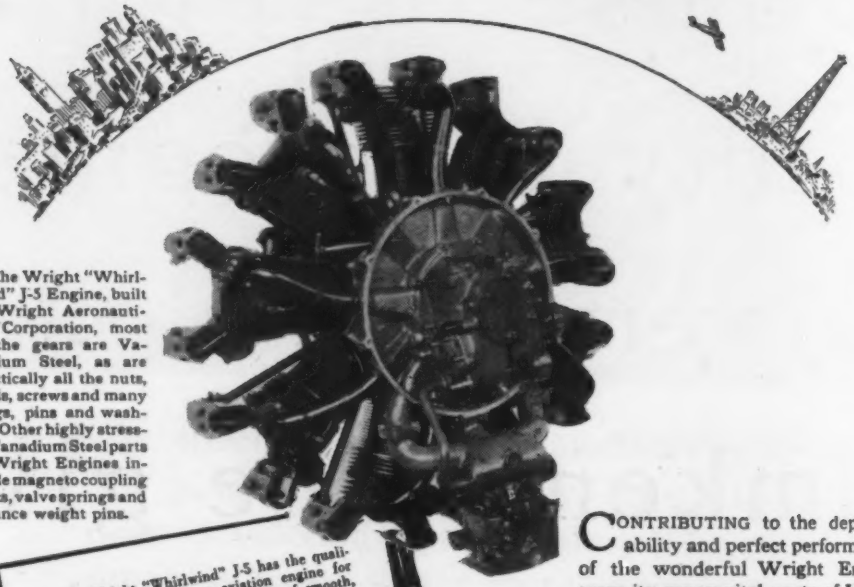

In the Wright "Whirlwind" J-5 Engine, built by Wright Aeronautical Corporation, most of the gears are Vanadium Steel, as are practically all the nuts, studs, screws and many plugs, pins and washers. Other highly stressed Vanadium Steel parts in Wright Engines include magneto coupling parts, valve springs and balance weight pins.

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Reprinted from "The Wright Engine Builder" —World's Record Number

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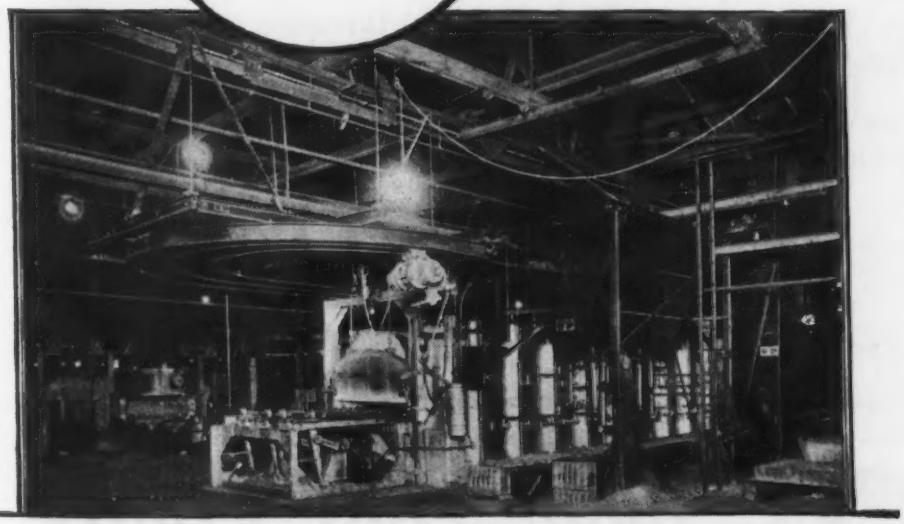

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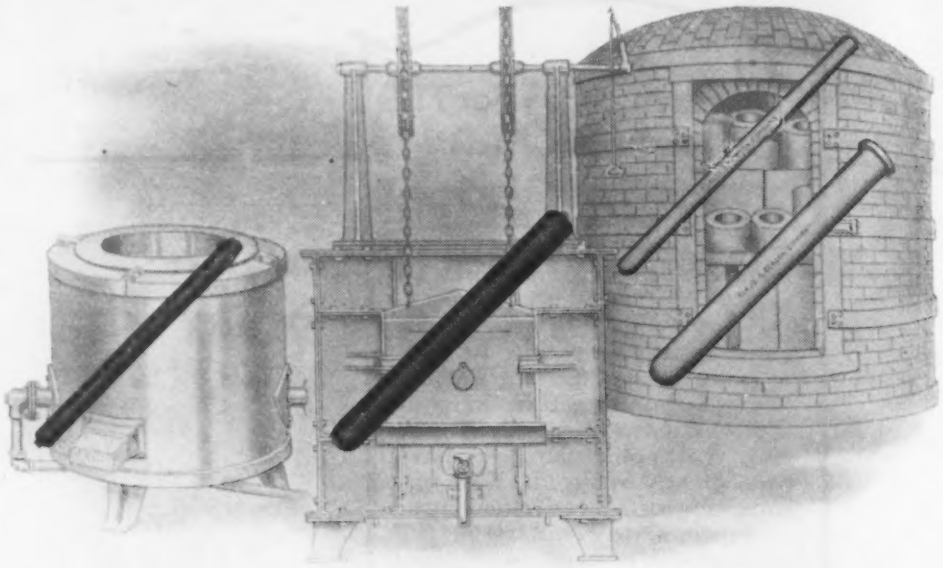

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The only thermo couple protecting tube which will protect a thermo couple from hot cyanide. It has an extreme long life and is guaranteed not to leak.

A trial will convince you that you have not used a real protecting tube in cyanide before you used a *Gordon's Service Cyanide Tube.*

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We will furnish this tube assembled with any make or type of thermo couple to fit your pyrometer.

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can be attached to any type of furnace and the precision of the VOLCRIT method secured in all hardening, tempering, annealing, or normalizing, treatments. Have you investigated the laboratory model? It is finding new uses every day.

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The Library Bureau makes the entire field of literature available to every member, distance is eliminated, for it will copy the desired information and send it to you. It also helps the busy man by supplying information without any expenditure of his time. The charge for this personal work is merely its cost.

Through the courtesy of Nelson Littell, we have secured an additional library service for members of the A. S. S. T. This service comprises the selecting and supplying of copies of current patents, on specified subjects, as they are issued by the Patent Office.

Mr. Littell will review the Official Gazette each week, selecting those patents on subjects desired by individual subscribers, and order separate copies mailed directly to them from the U. S. Patent Office. Subscribers may specify the field of patents which would be of interest, or they may supply a list of their products and manufacturing processes whereby Mr. Littell could judge as to what current patents would be of interest to them.

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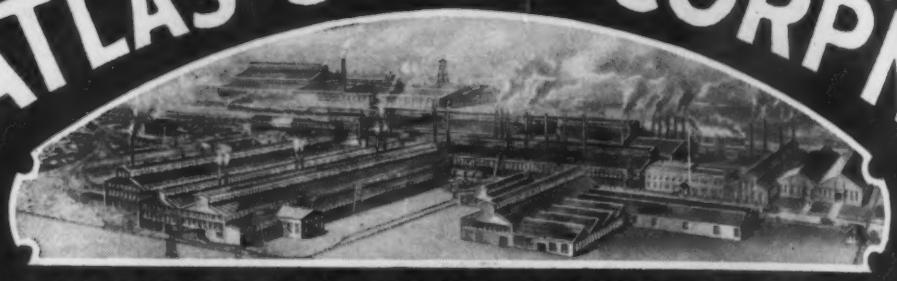

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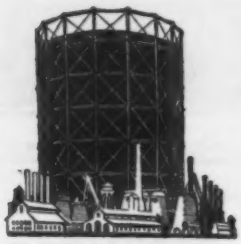

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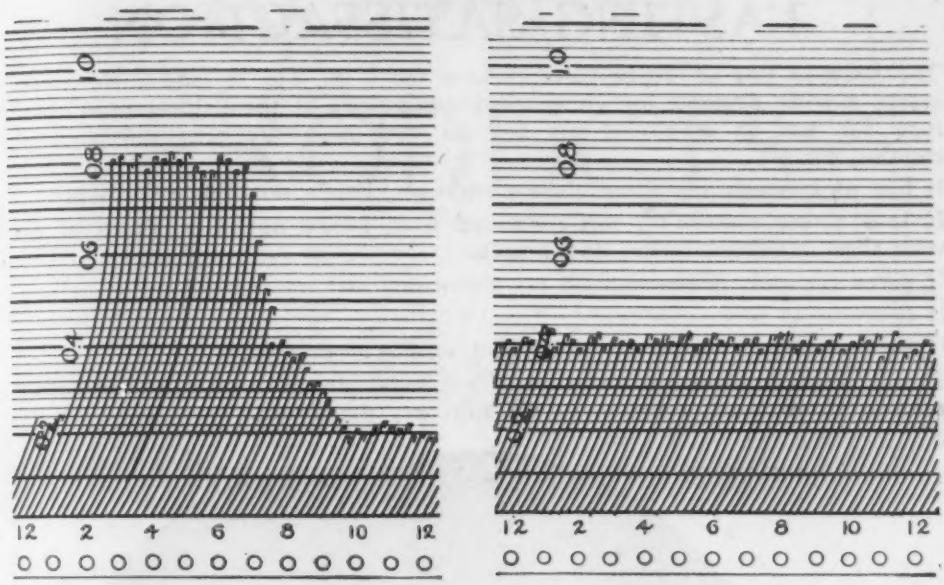

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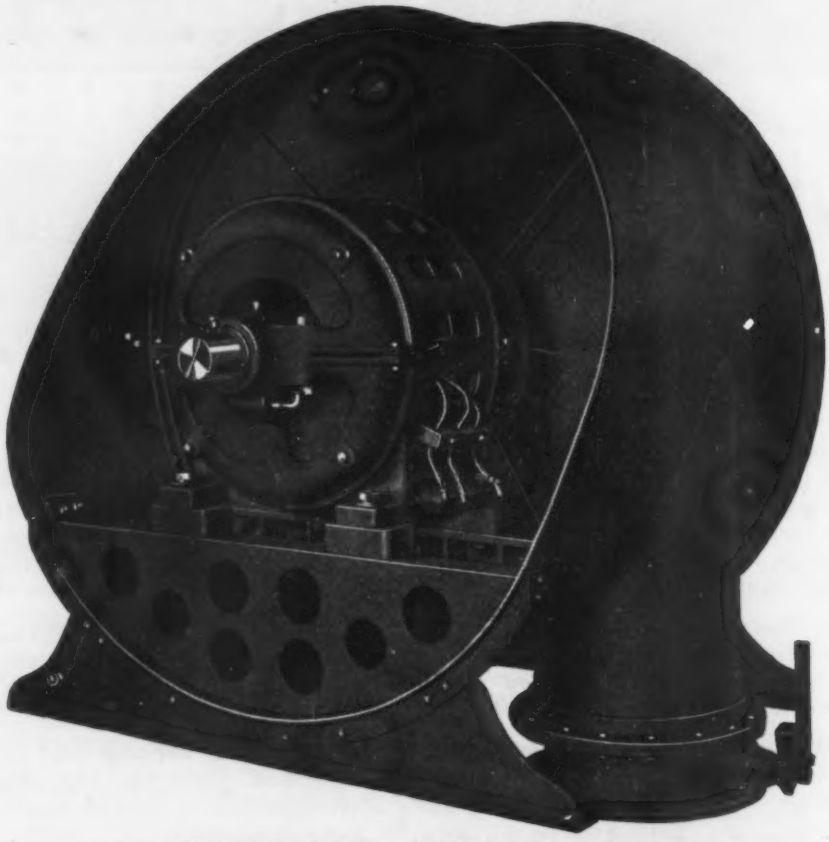

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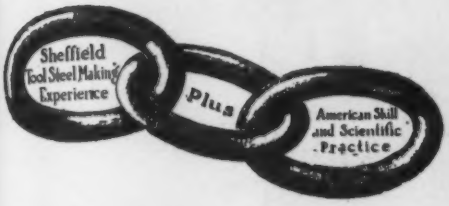

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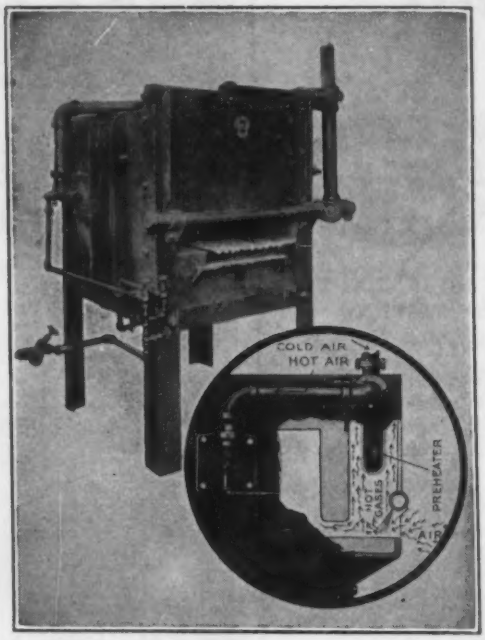

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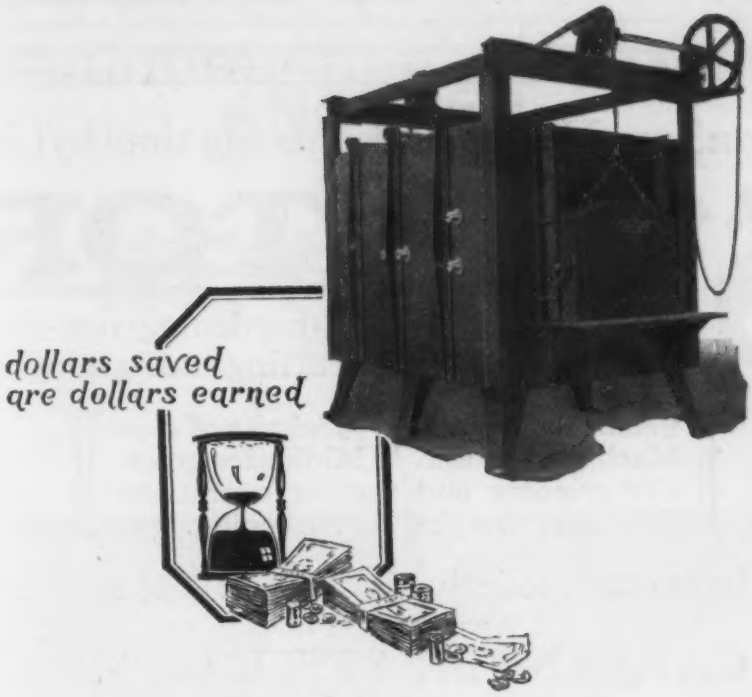

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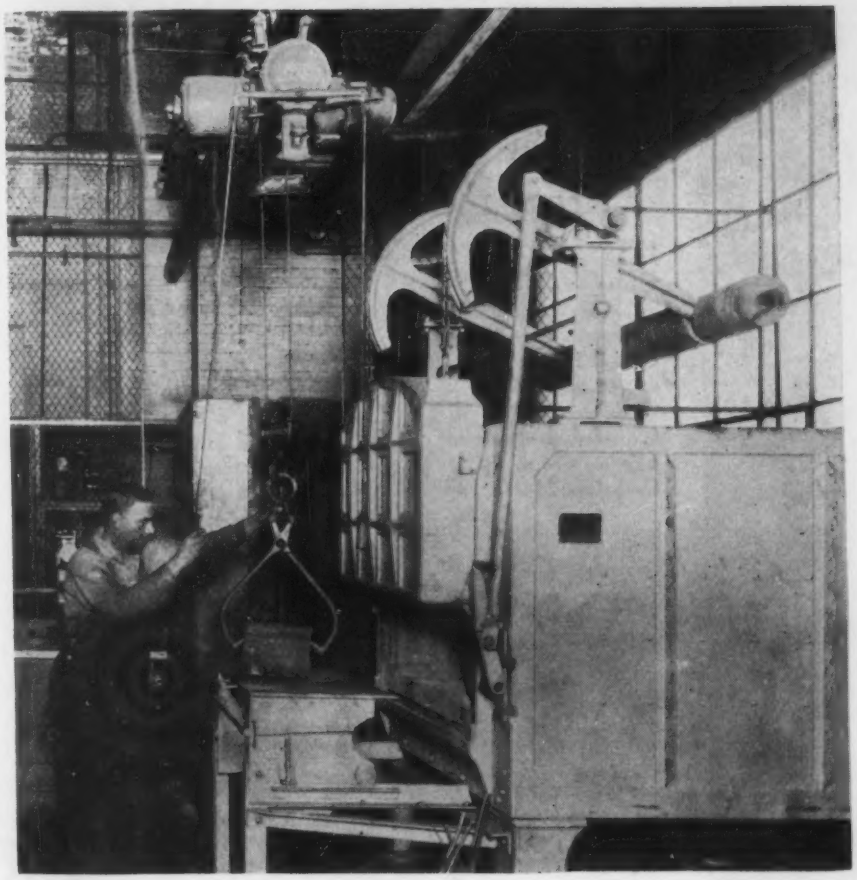

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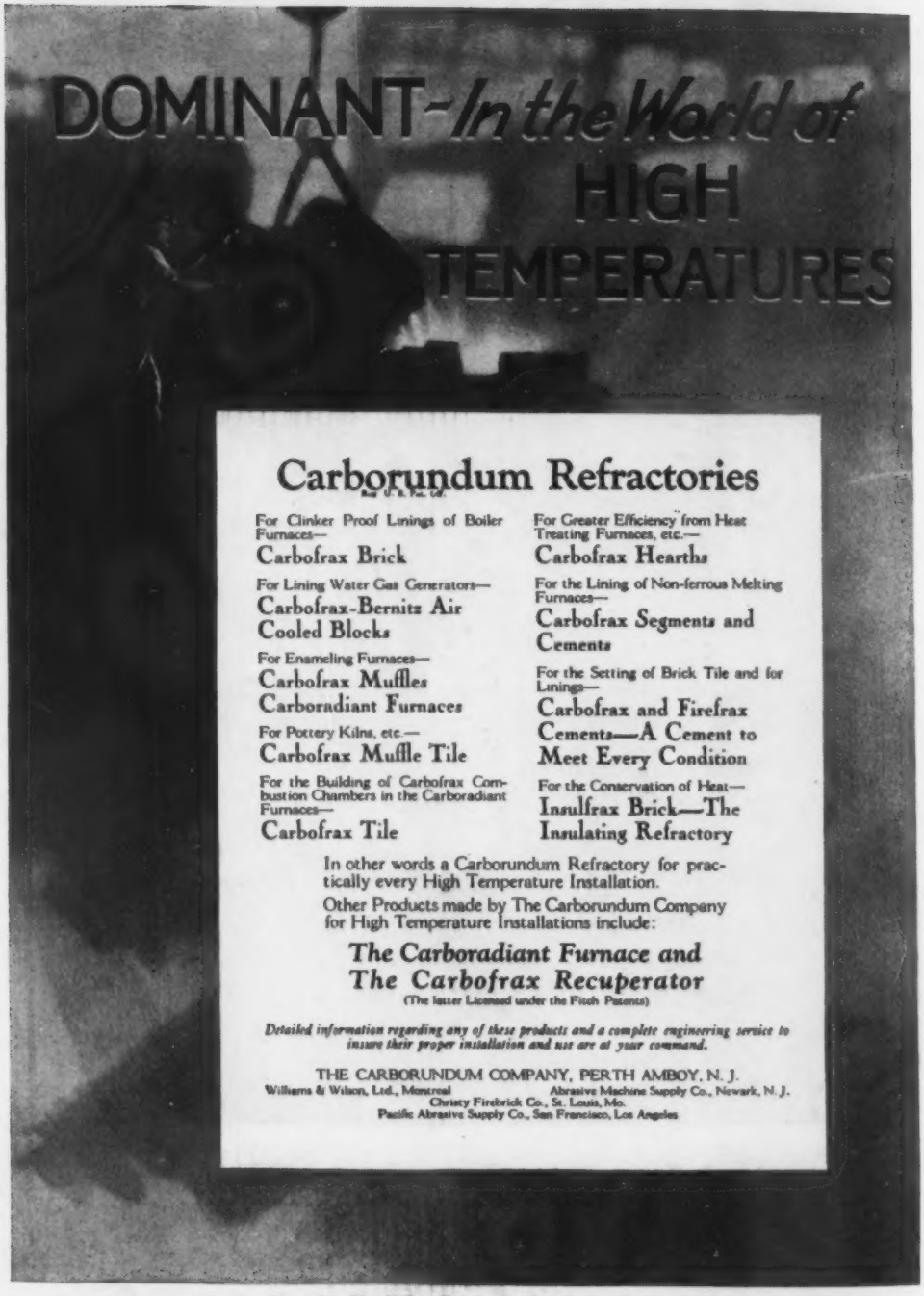

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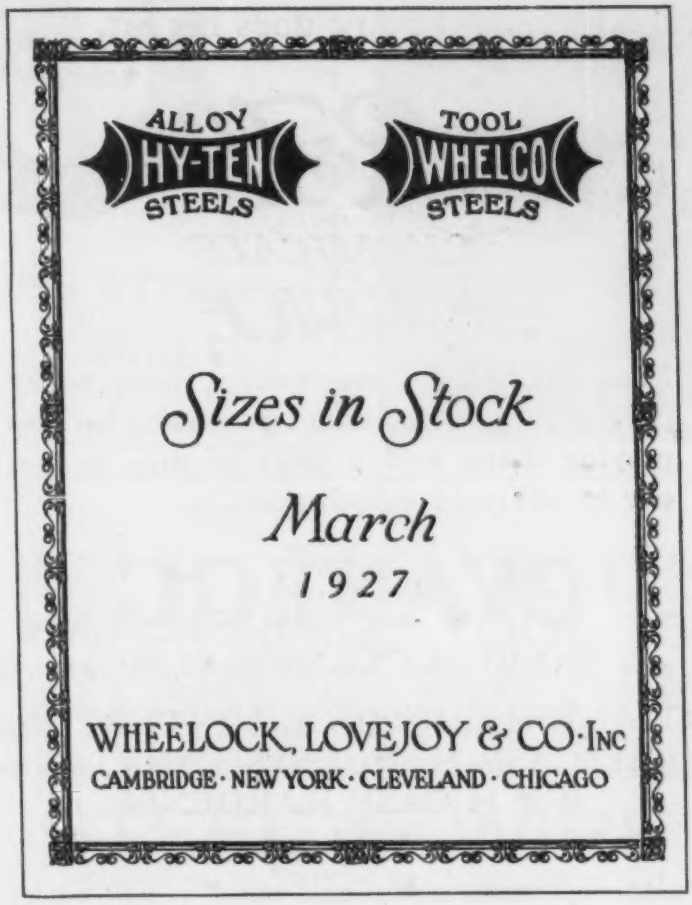

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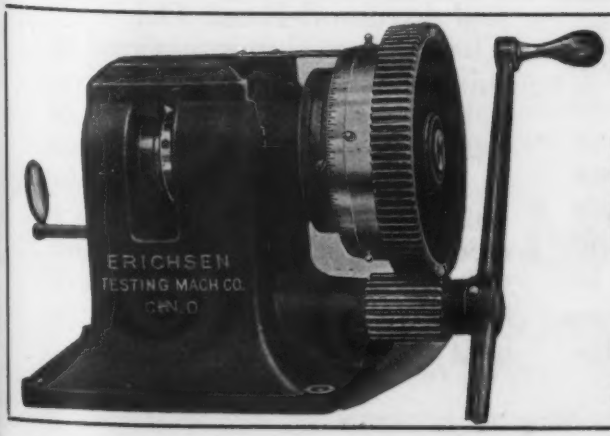

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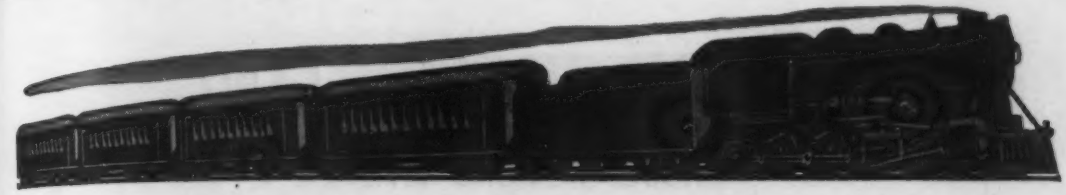
The information contained in this booklet is authoritative, being based on the results of half a century of experience in solving heat transfer problems of every nature. Every steel treater is sure to find valuable suggestions that will help secure better results in heat treating operations.



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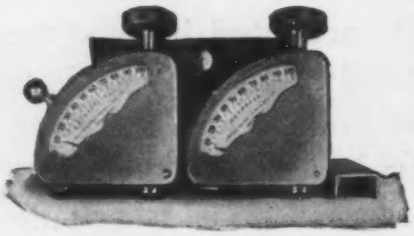

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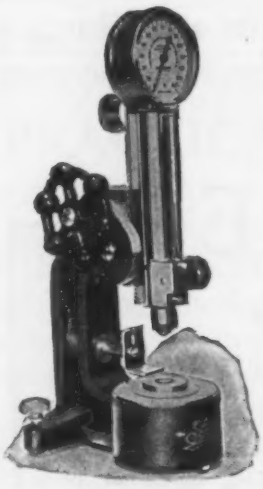
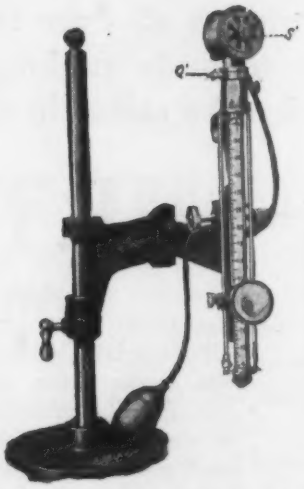


Scleroscope Model D



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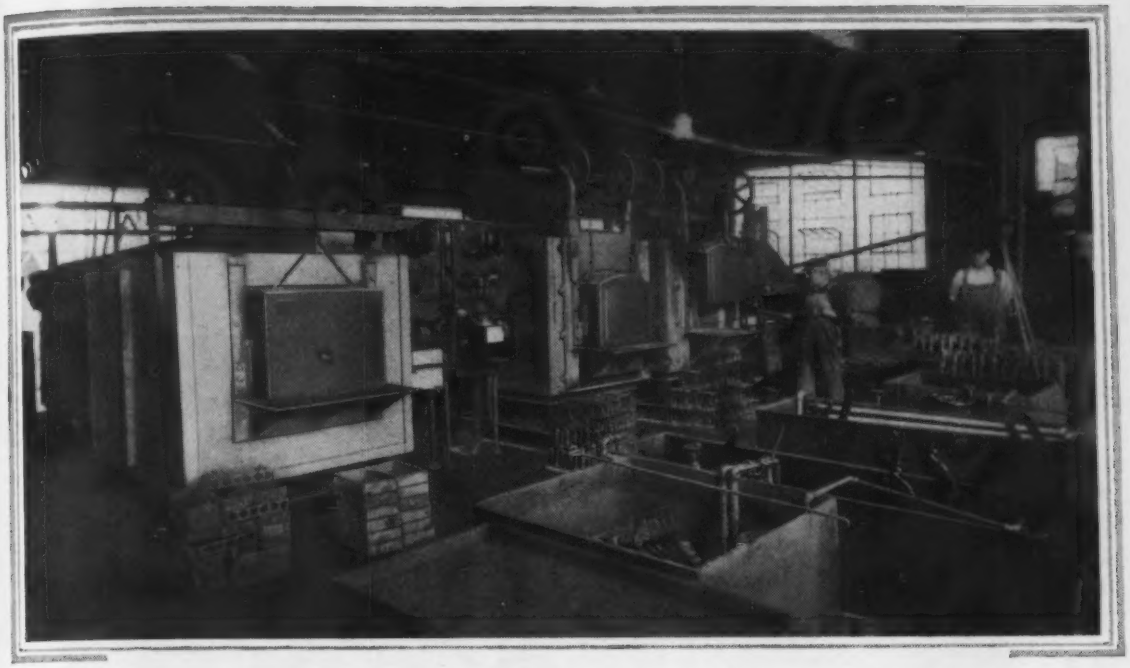

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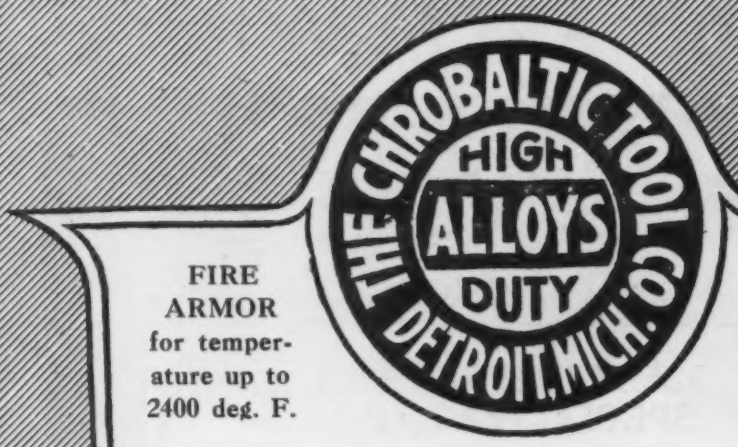

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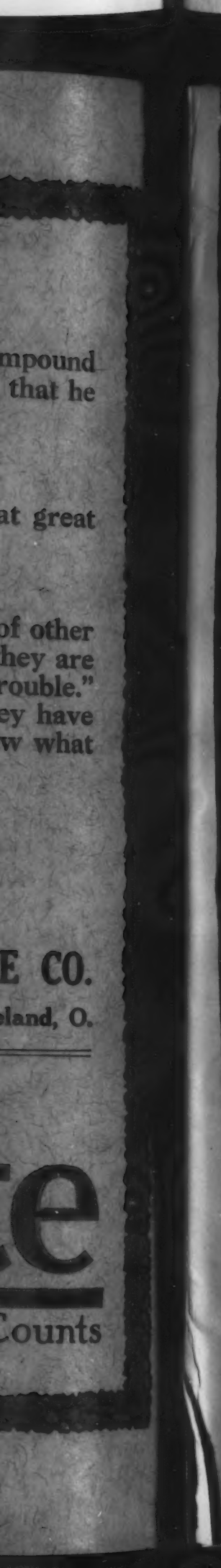
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